CHAPTER 9

WATER TREATMENT AND PURIFICATION

As a Utilitiesman, you are responsible for ensuring that an adequate supply of safe water is available for domestic and fire protection uses. In meeting this responsibility you must consider several factors, such as the selection of a water source, ways to develop the water source, contaminants you may encounter, and methods you can use to remove these contaminants. In this chapter, each of these considerations is discussed.

WATER SOURCE SELECTION

You must consider three factors for a water source: quantity, quality, and reliability.

SOURCE QUANTITY

Water sources developed for military use are referred to as water points. Water points are classified as follows:

1. Surface water (streams, lakes, and rivers)
2. Groundwater (wells and springs)
3. Seawater
4. Rain, snow, and ice

When selecting a water source, you must consider the amount of water available and what the demand is for water.

The amount of water that collects in any surface source depends on the amount of precipitation, the size of the drained area, geology, ground surface, evaporation, temperature, topography, and artificial controls.

The available water at a source can be estimated by using some simple calculations. To calculate the quantity of water (gallons per minute) flowing in a stream, use the following formula:

$Q = 6.4 \times A \times V.$

$Q = $ Quantity of water in gallons per minute (gpm).

$6.4 = $ A constant-There are 7.5 gallons of water per cubic foot. However, because of error in stream measurement, 7.5 has been reduced to 6.4.

$A = $ The area of the stream in square feet obtained by multiplying the width times the average depth of the stream.

$V = $ The velocity of the stream in feet per minute obtained by measuring the time it takes a floating object to travel a known distance.

An example of this calculation would be a stream having an average depth of 2 feet and a width of 16 feet, and a twig is noted to flow at 13.3 feet per minute. To find the amount of water flowing in the stream, you should work the equation as follows:

$Q = 6.4 \times A \times V$

$Q = 6.4 \times (2 \times 16) \times 13.3$

$Q = 6.4 \times 32 \times 13.3$

$Q = 2,723.84 \text{ gpm}$

To calculate the quantity of water in a lake or pond having little or no runoff, multiply the

surface area by the average depth. The answer is cubic feet. Multiply by 7.5 to obtain gallons at the water source. An example of this is a pond with an average depth of 7 feet and a surface area of 2,864 square feet. It is calculated as shown below:

$$Q = A \times D \times 7.5$$
$$Q = 2,864 \times 7 \times 7.5$$
$$Q = 150,360 \text{ gallons}$$

Lakes and ponds are usually located within the water table, and the hydraulics of the water feeding the lake or ponds are similar to that of wells. Therefore, a drawdown test, using a method similar to the one described below for wells, may be used to calculate the quantity of water. To perform the test, you should draw down the static water level to 1 or 2 feet and then record the recovery time. Also, devise a method to discharge the water being pumped so it does not return to the source during the test.

To calculate the quantity of water that can be supplied from newly constructed or existing wells, you must make a drawdown test. To perform this test properly, you must understand the hydraulics of a well.

Before being pumped, the level of water in a well is the same as the level of the water table in the water-bearing formation in which the well is completed. This is called the static level in the well and in the foundation. (fig. 9-1). The depth from the ground surface to the static water level should be measured and this distance used to describe its position. Thus if the water in the well
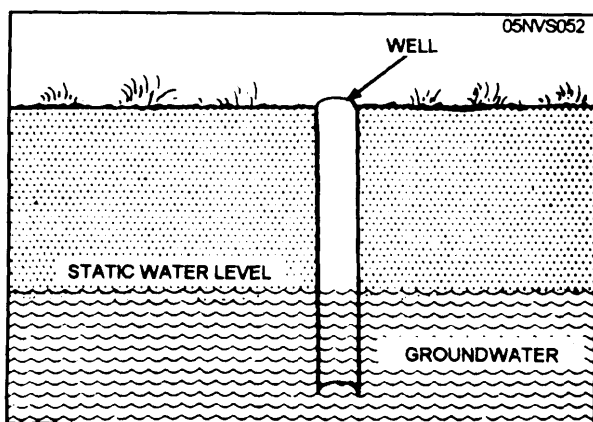
is 25 feet below ground, the static water level is said to be 25 feet for this well. Elevation of the static water level above mean sea level can also be used to describe its position.

When a well is pumped, the water level drops. After several hours of pumping at a constant rate, it stabilizes itself in a lower position. This is called the pumping level or dynamic water level for this rate of pumping (fig. 9-2).

The distance the water is lowered by pumping is called the drawdown. It is the difference between the static level and the pumping level. The drawdown in the well, resulting from pumping, lowers the water pressure in the well, but the surrounding water-bearing formation retains its original pressure. In response to this difference in pressure, water flows out of the pores of the formation into the well.

The water-bearing formation does not furnish its water all at once to the well being pumped. The flow of water into the well is held back by the frictional resistance offered by the formation to the flow of water through its pores. The resistance varies in each formation and is developed in direct proportion to the rate of movement or velocity of the water in the formation. The rate of flow, resulting from a given pressure difference, depends on the fictional resistance to flow developed in the formation. The term used to describe this characteristic of a porous material is *permeability.*

For a particular type of well, the yield of the well for any given drawdown is

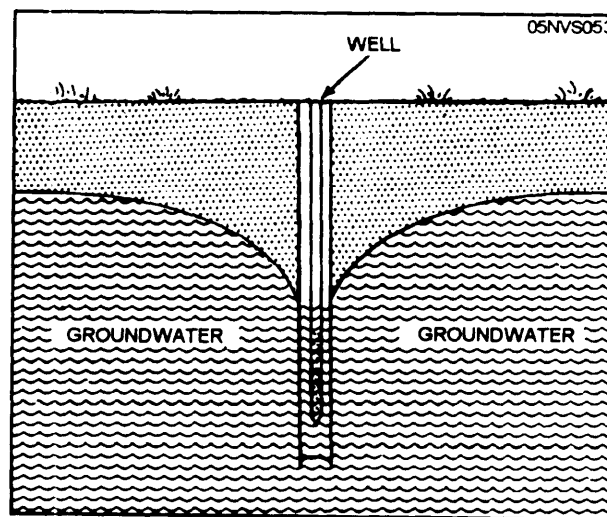Figure 9-1.—Static water level before pumping.
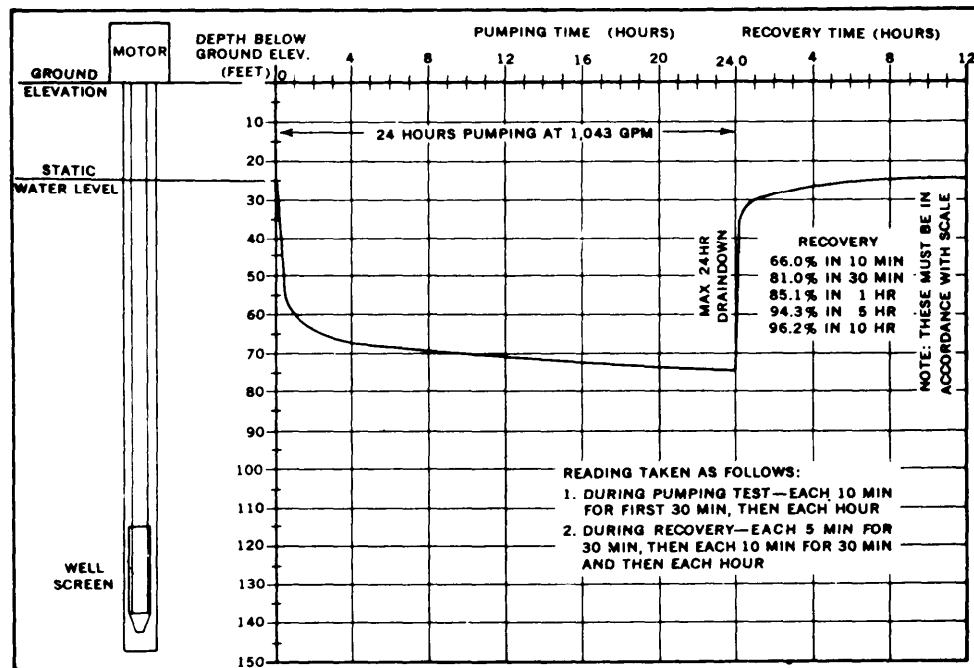

Figure 9-2.—Pumping level.

directly proportional to the permeability of the formation. This property of the formation varies through wide ranges, the value for a coarse sand stratum being several hundred times that of a fine sand stratum of the same thickness. It increases with the coarseness of the sand and decreases with the compactness of the material. It increases where the sand grains are more nearly uniform in size. It decreases when fine sand and silt fill the voids between larger particles. The permeability of a rock formation, like limestone, varies with the number and sizes of the fractures, crevices, and solution channels.

The measurements that should be made in testing wells include the volume of water pumped per minute or per hour, the depth to the static water level before pumping is started, the depth to the pumping level at one or more constant rates of pumpage, the recovery of the water level after pumping is stopped, and the length of time the well is pumped at each rate during the testing procedure. The testing described in this chapter is essentially the measurement of the hydraulic characteristics of a particular well.

The pump and power unit used for testing a well should be capable of continuous operation at a constant and variable rate of pumpage for a period of over 24 hours. It is important that the equipment be in good condition for an accurate test, since it is undesirable to have a forced shutdown during the test. The test pump should be large enough to test to the expected capacity of the well, even though this may be far beyond the amount of water required and may exceed the capacity of the permanent well pump. Pumping by airlift maybe a practical method, provided that meters are not used for measuring the flow. The test should run at least 24 hours. Longer tests, up to several weeks' duration, may be desirable to verify adequacy of the formation.

To determine the safe yield of the well, the pump should be operated at a rate that will cause only about 50 percent of the maximum possible drawdown. The drawdown should not exceed a point 5 feet above the topmost screen slot. For example, a 125-foot well has a static water level of 25 feet and a pumping level of 75 feet or a 50-foot drawdown. The satisfactory pumping level is 50 feet or 50 percent of the maximum drawdown. Therefore, a safe well capacity is established and maintained for that condition regardless of the yield. The safe pumping yield is the withdrawal rate that will not cause a lowering of the water table, and should cause no more than 50 percent of maximum drawdown. A chart, similar to the one shown in figure 9-3, should be

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Figure 9-3.—Well chart.

included in the test report. The complete test report will include the following:

1. Initial static water level

2. Pumping rates, at least every hour

3. Drawdown data, at least every hour

4. Rate of recovery

The simplest way to measure the water pumped is to catch it in a steel drum or other tank of known volume. The time required to fill the tank is determined as accurately as possible. The rate of pumpage in gallons per minute is then calculated. For reasonable accuracy, the tank should be large enough to hold the water pumped during a period of at least 2 minutes. This limitation makes the method practical only for relatively small wells, since large tanks will not usually be available.

Water meters offer a definite advantage in measuring the water being pumped. The amount of water pumped may be recorded from the meter at desired intervals. The total discharge may be recorded for any individual phase of the drawdown test.

The most accurate way to measure depth to the static level and to the pumping level in a well is with a chalked tape. A steel tape with a weight to make it hang straight is chalked at the lower end with blue carpenter's chalk and lowered into the well until 1 or 2 feet of the tape is submerged. The proper length to lower the tape may have to be determined by experiment. The wetted length of the tape shows up very clearly on the chalked portion of the tape. This length is subtracted from the total length lowered below the reference point; this gives the depth to water.

The drawdown observed during a well test is the difference in feet between the

Table 9-1.—Daily Water Requirements in Temperate Zone

Unit consumer	Conditions of use	Gallons per unit consumer per day	Remarks
Man	In combat:		
	Minimum ············	½ - 1	For periods, not exceeding 3 days, when operational rations are used.
		2	When field rations are used.
	Normal		
		3	Drinking plus small amount for cooking or personal hygiene.
	March or bivouac	2	Minimum for all purposes.
	Temporary camp	5	Desirable for all purposes (does not include bathing).
	Temporary camp with bathing facilities	15.	
	Semipermanent camp.	30 - 60	Includes allowance for waterborne sewage system.
	Permanent camp	60 - 100.	
Vehicle	Level and rolling country.	1/8 to 1/2	Depending on size of vehicle.
	Mountainous country	1/4 to 1	Depending on size of vehicle.
Hospital	Drinking and cooking.	10 per bed	Minimum, does not include bathing or water for flushing.
	With waterborne sewage.	50 per bed	

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pumping level and the static water level before pumping was started. The specific capacity of the well is the yield or discharge in gallons per minute divided by the drawdown in feet.

Water needs should be estimated, using per capita requirements and other controlling demands as factors in arriving at the estimate. Other controlling demands may be the water requirements for such items as fire protection, industrial uses, lawn sprinkling, construction, leakage, and water delivered to other activities, and vehicles. Table 9-1 shows the per capita daily water requirements for different situations, and the daily average requirements for vehicles. Table 9-2 indicates the requirements that may be needed for construction equipment. Compare the yield of the source with the needs of the activity.

SOURCE QUALITY

The quality of water is the ability of water to be potable and palatable (water that is safe to drink, being free of harmful characteristics that could cause odor, foul taste, bad color and/or disease).

Practically all water supplies have been exposed to pollution of some kind. The general growth of population and the increasing use of streams and other bodies of surface water for the disposal of wastes have been detrimental to water sources.

Impurities in water are either suspended or dissolved. The suspended impurities are usually more dangerous to health. They include mineral matter, disease organisms, silt, bacteria, and algae. These must be destroyed or removed from water that is to be consumed. While some of these impurities can be seen by the naked eye, others

Table 9-2.—Quantity and Quality of Water Needed by Construction Equipment

Equipment	Size	Quantity	Purity of water
Rock crusher	. . . . . 225-T.	60,000 gpd	No special purification. Seawater usable.
Concrete mixers	. . . .	18,000 gpd	Potable; minimum of organic matter. Acid alkali free. Seawater may be
Concrete paver	. . . .	60,000 gpd	used but decreases concrete strength by 20%. Extra cement may be used to offset this effect.
Asphalt plant	. . . . .	1,000 gph	Alkali free. Low sulfates.
Steam jenny	. . . .	. . . .	Potable; low calcium and magnesium.
Steam boiler.	. . . . . 200-hp.	2,000 gpd	'' '' '' ''
	w/receiver	1,000 gpd	'' '' '' ''
Three car heater (for asphalt plants).	. . . .	50 gph	'' '' '' ''
Water distributor . . .	. . . . . 1,000 gal	1,000 gal per 100 yd of 8 ft road.	No special purification. Salt water acceptable.
Compaction	. . . .	Variable	Any available water accepted. Seawater actually preferable for certain jobs.
Vehicle radiators . . .	. . . .	Variable	Potable; calcium and magnesium lower than 400 ppm.
Asphalt rollers	. . . .	Variable	Potable; free of organic matter.

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can be detected by laboratory tests only. Table 9-3 identifies some of the common impurities in water and summarizes their effect on water quality.

Water samples must be forwarded to a laboratory for complete mineral or bacteriological analysis.

The factors that affect and determine the quality of water, such as physical, chemical, biological, and radiological contamination, are discussed later in this chapter.

SOURCE RELIABILITY

The reliability of a water supply is one of the most important factors in the selection of a water source. The information gathered during the water reconnaissance may indicate a source of sufficient supply only to have the source dry up during periods of no rainfall. Study the hydrological data to determine the variations that may be expected at the water source.

Geological formations influence the reliability of a groundwater source. The amount of water flowing and the rate of flow maybe controlled by geological layers. The amount of water within a water table may be limited by impervious formations, as shown in figure 9-4. Therefore, it is important that information on the characteristics and properties of the geological

Table 9-3.—Common Impurities in Water

Suspended Impurities			Organisms...	Some cause disease
			Algae...	Cause taste, odor, color, turbidity
			Suspended solids.............................	Cause murkiness or turbidity
Dissolved impurities	Salts	Calcium and magnesium	Bicarbonate.....	Causes alkalinity, hardness
			Carbonate........	Causes alkalinity, hardness
			Sulfate..............	Causes hardness
			Chloride...........	Causes hardness, corrosive to boilers
		Sodium	Bicarbonate.....	Causes alkalinity
			Carbonate........	Causes alkalinity
			Sulfate..............	Causes foaming in steam boilers
			Fluoride...........	Causes mottled enamel of teeth
			Chloride...........	Causes salty taste
	Iron		....	Causes taste, red water, incrustation on metals
	Manganese		....	Causes black or brown water
	Vegetable dye		....	Causes color, acidity
	Gases		Oxygen...	Causes corrosion of metals
			Carbon Dioxide.................................	Causes acidity, corrosion of metals
			Hydrogen sulfide...............................	Causes odor, acidity, corrosion of metals
			Nitrogen...	No effect

formations be studied when a ground source is being considered.

It may be necessary to consider numerous other factors that may affect the reliability of the source. For one example; Lake Bonnie Rose, U.S. Naval Station, Adak, Alaska, is an ample source of cool, clear water, being distributed by gravity. However, the relatively high elevation of the lake results in excessive pressure at the station. Pressures are controlled by pressure-reducing valves. The valves sometimes fail in service, resulting in damage to the water system.

Reliability of the source is further increased as the requirements for items that are subject to breakdown decrease (pumps, treatment plants, and so on).

Legal advice may be necessary when selecting a water source as the laws regulating and controlling water rights may vary considerably. The title to ground and surface water in the United States is usually regulated at the state level. Navigable waters having interstate traffic are under federal control. Some difficulty was experienced in Vietnam by SEABEES in securing water rights to surface streams. These waters were used for flooding of rice fields, and local control denied the use of these sources as water supplies.

Legal advice may also be required in securing the right for waterlines or powerlines to cross property. To cite one example, a waterline serving a naval air facility in Sicily was completed, except for a section crossing an irrigation ditch. Final completion of the waterline was delayed for

2 months, waiting to obtain the right for the waterline to cross the ditch.

DEVELOPMENT OF WATER SOURCES

Development of a water source includes all work that increases the quantity and improves the quality of the water, or makes it more readily available for treatment and distribution. The development of surface water sources, springs, and seawater sources is considered in this section.

In developing a source, dams, floats, galleries, and similar improvements may be used to increase the quantity and quality of the water. Elaborate developments should be avoided; simplicity brings more rapid results. A temporary water source should not be converted into a permanent one until the area has been reconnoitered for a source requiring less development. All intake hoses or pipes should be equipped with an intake strainer regardless of the clearness of the water source. Suction strainers should be protected from floating debris that may damage, clog, or unnecessarily pollute them. Proper anchorage of suction lines and strainers prevents (1) loss of prime, (2) punctured or kinked lines, and (3) damage to strainers. Water at the intake point should be as clear and deep as possible. The strainer on the suction hose is placed at least 4 inches below the water level. This precaution reduces the possibility of the strainer becoming clogged with floating debris, or the prime being lost because of air getting into the suction line.

SURFACE WATER DEVELOPMENT

Of the total amount of rainwater that falls upon the land surface of the earth, only a comparatively small part is absorbed by the soil. By far the greater part of it runs off the surface of the ground and is carried out to the sea by way of streams and rivers or remains stored in natural lakes and ponds and in artificial lakes and impounded reservoirs. The methods by which water supply is derived from the surface are (1) by damming of streams or rivers, (2) by using the flow from streams, (3) by pumping directly from surface streams, (4) by collecting water from the roofs of buildings, (5) by providing catchment areas for the collection of rainwater into specially constructed cisterns, (6) by solar distillation, (7) by power distillations, (8) by freezing, and (9) by electrodialysis.

For normal field water supply, surface water is the most accessible type of water source. This
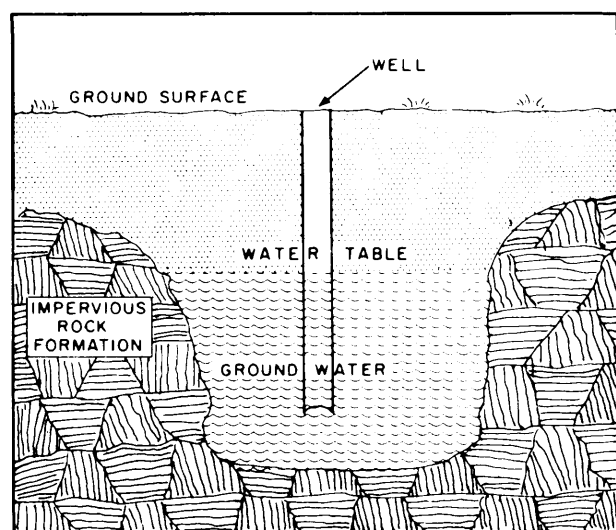
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Figure 9-4.—Limitation of water by rock formation.

source also lends itself readily to the purification equipment common to most engineer units. Surface water is the most easily developed source of water. Methods of constructing intake points for land surface water sources are discussed below.

If the stream is not too swift and the water is sufficiently deep, an intake may be prepared quickly by placing the intake strainer on a rock. This will prevent clogging of the strainer by the streambed and provide enough water overhead to prevent the suction of air into the intake pipe. If the water source is a small stream or shallow lake,
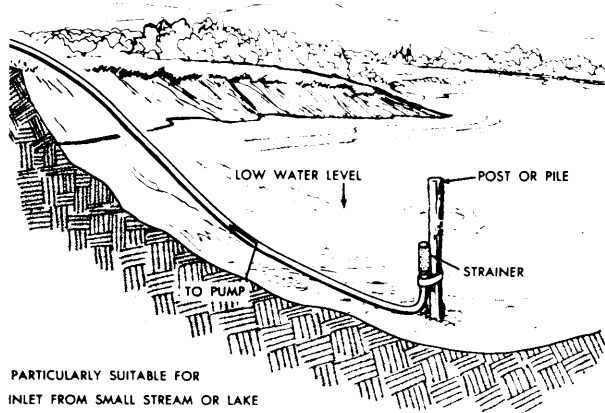
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Figure 9-5.—Direct intake with hose on bottom of water source.

the intake pipe can be secured to a post or pile as shown in figure 9-5.

When a stream is so shallow that the intake screen is not covered by at least 4 inches of water, a pit should be dug and the screen laid on a rock or board placed at the bottom of the pit. Pits dug in streams with clay or silt bottoms should be lined with gravel to prevent dirt from entering the purification equipment (fig. 9-6). The screen is surrounded by gravel to prevent collapse of the sides of the pit and also shield the screen from damage by large floating objects. The gravel also acts as a coarse strainer for the water. A similar method may be provided by enclosing the intake screen in a bucket as shown in figure 9-7.

The level of the water in small streams can be raised to cover the intake strainer by building a dam.

In swiftly flowing streams, a wing or baffle dam can be built to protect the intake screen without impounding the water.

Floats made of logs, lumber, sealed cans, or empty fuel drums can be used to support the intake strainer in deep water. Floats are especially useful in large streams where the quality of the water varies across its width or where the water is not deep enough near the banks to cover the intake strainer. The intake point can be covered by an adequate depth of water by anchoring or stationing the float at the deep part of the stream. The intake hose should be secured to the top of the float, allowing enough slack for movement
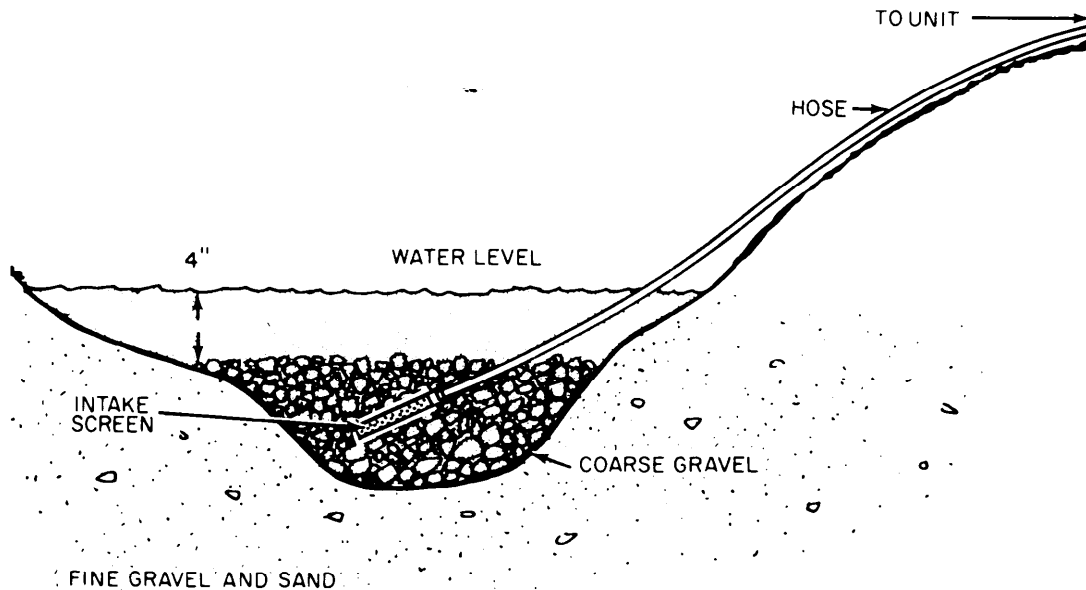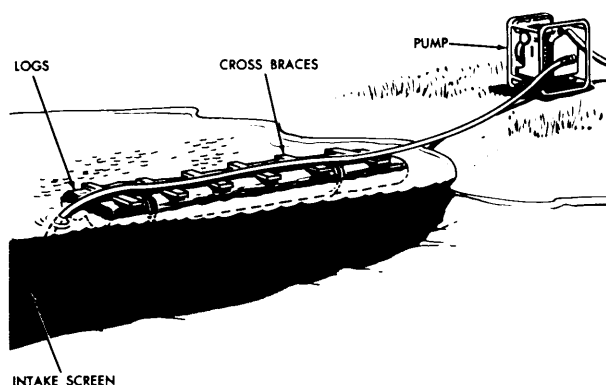

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Figure 9-6.—Surface intake with hose buried in gravel-filled pit.

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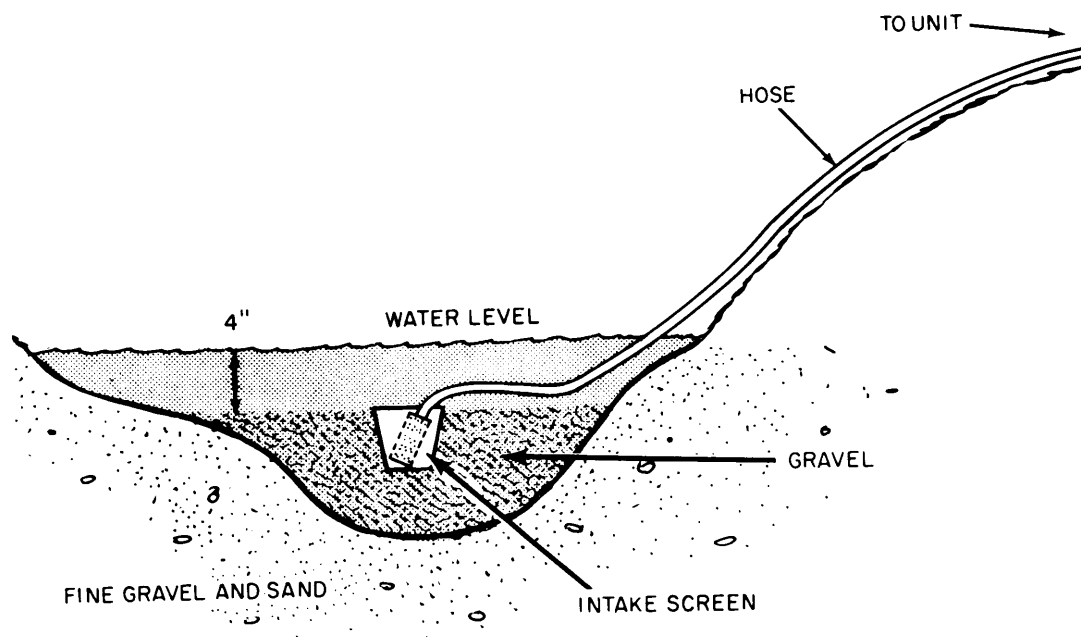
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Figure 9-7.—Use of bucket on end of surface intake.

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Figure 9-8.—Float-type surface intake.

of the float. If support lines are used to secure the float to the banks, the position of the float can be altered to correspond to changes in depth by manipulation of the lines. The chief advantage of a float intake is the ease with which the screen can be adjusted vertically (fig. 9-8).

Water from muddy streams can be improved in quality by digging intake galleries along the bank. A trench is dug along the bank deep enough so that water from the stream percolates into it so it intercepts ground water flowing toward the stream. The trench is filled with gravel to prevent the sides from collapsing. The intake strainer is placed in the gravel below the water table (fig. 9-9). The amount of work required to produce
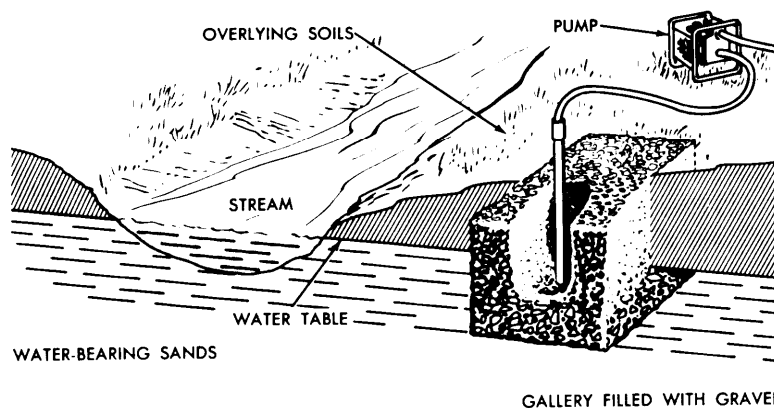
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Figure 9-9.—Gravel-filled gallery intake.

the gallery is justified by a reduction in the amount of chemicals needed to coagulate the water, the elimination of the necessity of frequently backwashing the filter, and the higher quality of water obtained.

GROUND WATER DEVELOPMENT

Moisture is held beneath the surface of the earth in three zones: (1) the zone of soil moisture, where water is temporarily held in pore spaces by capillary action or other soil conditions; (2) the zone of aeration or zone of percolation beneath the soil layer, where both water and air are present in the pore spaces; and (3) the zone of saturation, where all spaces are filled with water. *Ground water is* the term customarily used for the underground water in the saturated zone.

One possible objection to an underground water supply is that the water may be excessively hard. This condition may occur because of the percolation of the water through mineral deposits from which water-hardening constituents are leached or extracted. On the other hand, an underground supply generally has the advantage of requiring less treatment because of the natural removal of impurities as the water passes through various underground soil formations. However, these conditions are general; some mineral deposits do not contribute to hardness, and some underground formations may not be of the type that effectively removes objectionable material.

Many times it is advantageous to use shallow ground water sources or percolated waters adjacent to a turbid surface water. Well points are issued in 2-inch diameters and 54-inch lengths. A drive cap is placed over the thread and the well point is driven into the ground with a sledge. Successive sections of pipe, each 5 feet long, are added and driven until the screen is well within the water-bearing media. Several well points may be connected in parallel to supply sufficient water to the raw water pump. In developing drive point sources, it must be remembered that the practical limit of suction lift of the pumps issued with field equipment is 22 to 25 feet at sea level. Suction-lift pumps can be used, therefore, only where the pumping level in the well will be within the limit of suction llift, or 22 to 25 feet below the position of the pump. At 5,000 feet above sea level, the practical limit of suction lift is only 20 feet. It should be noted that since a suction-lift pump must create a partial vacuum in the suction line, it is necessary that the line be absolutely airtight if the pump is to function properly.

Springs yielding 20 gallons per minute or more of water can be used as a source of field water supply if properly developed. Springs may be developed by enlarging the outlet of the spring and by damming and conducting water to storage. To reduce possible pollution, springs should be cleared of all debris, undergrowth, top soil, loose rocks, and sand.

Water that flows from rocks under the force of gravity and collects in depressions can be collected in boxes or basins of wood, tile, or concrete. The collecting box should be large enough to impound most of the flow. It should be placed below the ground level so only the top is slightly above the surface. The box should be covered tightly to prevent contamination and lessen evaporation. The inlet should be designed to exclude surface drainage and prevent pollution. This requires fencing off the area and providing proper drainage. Figure 9-10 shows a spring inlet protected in this manner. The screen on the overflow pipe prevents the entrance of insects and small animals. Another screen on the intake pipe prevents large suspended particles being ingested by the pump used to distribute the springwater. This prevents mechanical failure or reduces it to a minimum.

The flow of water from a spring located on a steep slope of loose earth can be obtained by the following two methods.

● Constructing deep, narrow ditches leading from the spring to the point of collection.

● Constructing pipeline tunnels from the spring to the collecting points. Pipe of large diameter is more suitable for this purpose. The water from the tunnels can be trapped by constructing a dam at the point of collection.

Digging is a more positive and more economical method of developing a spring than blasting. You must proceed with great caution if you use exposives to develop the yield from springs. Blasting in unconsolidated rocks may shift the sand or gravel in such a way as to divert the spring to a different point.

The method used for the development of springs as a water source will depend upon the extent and characteristics of the flow. Thermal (hot) springs should not be developed since their waters are likely to be highly mineralized.

Regardless of the type of construction, all springs must be covered. Surplus water should be piped from the structure so surface water cannot
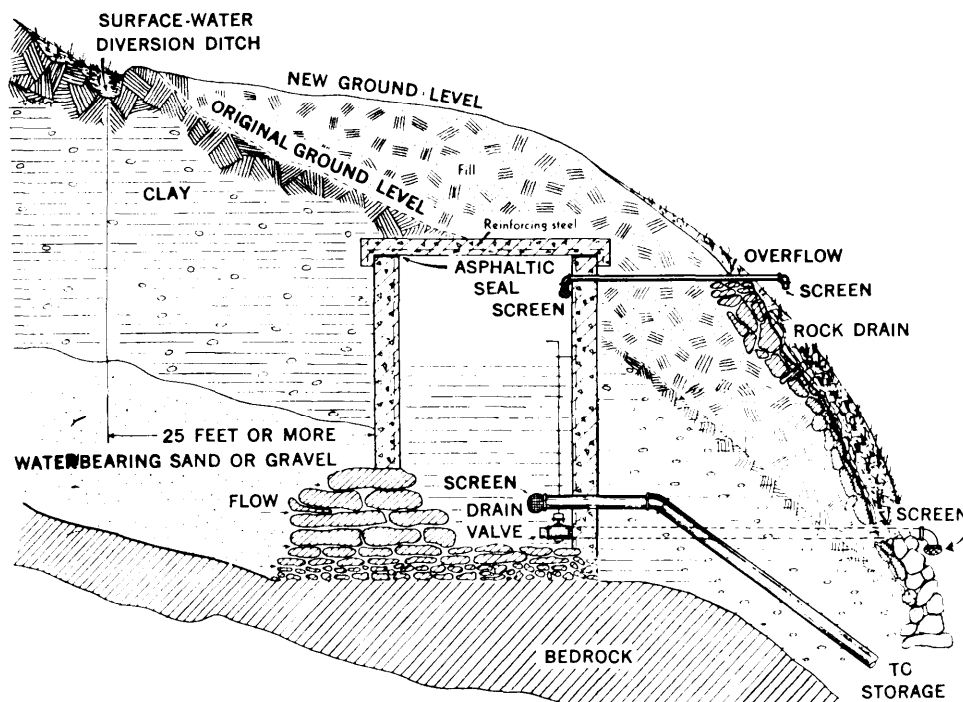
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Figure 9-10.—Protection of spring from surface contamination.

enter the spring during periods of flood. It is not necessary to ventilate spring structures; therefore, all openings should be avoided, except for an inspection manhole fitted with a tight, locked cover.

When ground and surface water supplies are inadequate or cannot be used, ground water supplies are developed by constructing wells. Wells are classified into five types, according to their method of construction. These are dug, bored, driven, jetted, and drilled wells. Each type of well has its particular advantages, which may be ease of construction, type of equipment required, storage capacity, ease of penetration into certain types of formations, or ease of safeguarding against pollution.

In the event of chemical, biological, and radiological operations, it is important to note that ground water would probably remain essentially uncontaminated by airborne or surface dissemination, in contrast to surface water, which could become severely contaminated. This does not mean that ground water is always pure and safe to drink. It can be naturally contaminated or could, in some cases, become contaminated with CBR agents. Well water should be thoroughly tested before use.

The production of ground water involves the method of recovery of water stored in the zone of saturation below the waterline or water table. The ground water table does not always remain at the same elevation, as it is controlled by rainfall, tides, the pumping rate from wells, and so forth.

A *dug well* is a large diameter well, seldom less than 3 feet in diameter, excavated with hand tools, and lined with brick, stone, steel, wood cribbing, or tile. That portion of the lining through the water-bearing formation is porous. This shallow type of well is usually dug from 20 to 40 feet deep, depending upon favorable location for water. Because of the large opening and perimeter to be protected against the incursion of surface drainage, dug wells are easily polluted by surface wash.

Bored wells are constructed in soft water-bearing formations that will not cave in while the hole is being bored. They are usually bored with hand or powered earth augers to a depth ranging from 25 to 60 feet without caving in.

Jetted wells are suitable in soft, unconsolidated, alluvial deposits. The well consists of an inner tube which is a drilling or jetting tube and an outer tube which is the well-casing. A

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power-driven pump with suitable hose attachments supplies continuous water pressure during drilling. One type of rig uses a block and tackle or a tripod for controlling the tools and casing. Larger rigs have a mast and hoisting block and use engine power for handling casing, drive weight, and pump. Water is led into the well through a small diameter pipe and forced downward through the drill bit against the bottom of the hole. The stream loosens the material, the finer portion of which is carried upward and out of the hole by the ascending water. During the drilling, the jet or drill is turned slowly to ensure a straight hole. Casing is sunk as fast as drilling proceeds. In softer materials, by using a paddy or expansion drill, a hole may be made somewhat larger than the casing. The casing then may be lowered a considerable distance by its own weight. Ordinarily a drive weight is needed to force it down. As a rule, one size of casing is used for the entire depth of the well. It is difficult to drive a single string of casing beyond 500 to 600 feet by this method. If a well is sunk much deeper, an additional string of smaller size must be used. In fine-textured material the hole often may be jetted to the full depth and the casing inserted afterward. The wall of the hole becomes puddled by the muddy water so it will stand alone.

A *driven well* is constructed by driving a pointed screen, or drive point, and attached pipe directly into a water-bearing formation. The finished well consists of a series of lengths of pipe fitted at the upper end with a pump and the lower end with a sand screen through which the water is admitted. The drive point consists of a perforated pipe with a mild steel point at its lower end to break through pebbles or thin layers of hard material. As the drive point is driven down, succeeding sections are screwed into place. These sections continue until the water-bearing formation is reached. The pump then is attached, and after the well has been developed, it is ready for use. Drive point wells usually range in diameter from 1 1/4 to 2 inches, but larger sizes up to 4 inches also are made. The larger sizes, although of greater weight and more difficult to drive, have the advantage that deep-well pumps can be used when necessary. The smaller sizes, because of their lesser weight and greater portability, are valuable for determining the depth of water-bearing formations and for test yields at shallow depths. The depth of the well is limited by the formations encountered and by the type of pump available. For small wells, the ground water level must be within 25 feet of the surface because suction pumps generally are used. If small self-priming centrifugal pumps are used, the lift must be less than 25 feet. If 2-inch or larger pipes are used, it is possible to lift water from a greater depth by installing a cylinder-type pump near the water level.

The following conditions are necessary for successful driven wells. The formation into which the point is being driven must not be too hard and compact. The distance to ground water must not exceed the lift of the pumps available. The water-bearing formations must have moderately high permeability to provide adequate yields in small-diameter wells. The wells must be developed properly to obtain sufficient water.

Chief disadvantages against general use of driven wells are as follows. Construction is laborious and slow when tightly compacted soils are encountered. Driving is destructive to well equipment; points frequently are stripped of mesh; pipe is bent and broken. Couplings frequently are belled by the force of the hammer blows. Belled joints always leak air and either render the well useless or seriously impair the yield of water. Yields are small from any one well point. As many as five points connected in series may be required to operate a power pump to capacity.

Successful construction of driven wells depends upon close observation and correct interpretation of events (occurring while driving) by the well driver. Accurate interpretation of such details as the penetration made with each blow, the drop and rebound of the monkey, the sound of the blow, and the resistance of the pipe to rotation enables the experienced well driver to determine the character of the materials being penetrated. An approximation of the geological section of the well can be obtained by recording these observations. Study of the logs for successive wells, coupled with a study of the results obtained from each well, assists in developing trained well drivers with each successive well.

Although a well site may have been properly selected, the strata correctly interpreted, and the presence of water accurately judged, wells may fail to yield water merely because they have not been pumped to clear the fine sediment from around the screen. When the presence of water is suspected, a simple test is to pour water into the well. If the screen is in dry sand, the water sinks downward and seeps into the formation, but if the screen is in saturated sand, the level of the added water remains nearly stationary or quickly sinks to a static level. Also the quantity

of water that can be poured into the well is an index of the well capacity when pumping; when saturated, the sand yields its contents as freely as it absorbs water. Often the raising or lowering of the pipe a foot or more brings a greater length of the screen into contact with the water-bearing stratum and results in a great increase in yield.

There are two methods of drilling wells, one is the hydraulic rotary and the other is the cable-tool percussion. Drilled wells tend to be the most complicated and require a lot of equipment. In most cases Equipment Operators will be called upon to place drilled wells. The Utilitiesman may be called upon to install pumps and plumbing when the drilling is complete. Development of this type of well will then proceed in a similar manner as any other type of well.

ALTERNATIVE WATER SOURCES

In some regions of the world there is not enough surface or ground water available to support the demands for domestic and fire protection water needs. In these areas it may be necessary to develop alternate sources of water. Rainwater, snow, seawater, water barges, and mobile tanks are a few of the alternate water sources that may be considered.

In tropical regions there is an abundance of rainwater with a rapid rate of surface runoff. The construction of collection surfaces can be a solution to water needs.

For temporary or emergency water supplies, collecting surfaces may be constructed by the use of tarps, wooden platforms, metal surfaces, and so on. Usually, however, surfaces constructed for other purposes, such as building roofs, may be used.

More permanent rainwater catchment areas will be cleared, graded, and given an application of cement or other impervious mixture. The catchment area should be located at least 100 feet from any source of subsurface contamination (septic tanks, cesspools, and so on), and as far from other sources of pollution (dust, soot, and so on) as possible. The catchment area and impounding basin should be enclosed by a fence.

Collected waters should be carried by gravity or pumping to closed stowage reservoirs. As rain falls toward the earth, it absorbs dust and such gases as carbon dioxide and oxygen, and, therefore, must be considered unsafe for consumption until treated. Filtration and disinfection are the minimum required treatment.

In some locations water may be so hard to obtain or polluted that it would not be economical to develop any source. In this case, water barges or mobile tanks may be used. Barges or mobile tanks can be filled from ships, tank trucks, or other well points located some distance away. It is important to note that all mobile containers are a temporary water source. Disinfection of their surfaces that will come in contact with potable water is required.

In northern arctic areas where deep wells cannot be sunk through the thick layers of permafrost, and the surface sources are frozen solid, water must be obtained by melting snow or ice. Ice is preferred to snow because it will yield more water for a given volume. Snow or ice may be contaminated. Therefore, all melt produced should be treated before drinking. Approximately 5 cubic feet of snow is required to yield 1 cubic foot of water. In emergencies, personnel can eat small quantities of snow. This snow should be placed in the mouth, rather than being sucked, to prevent chapped or cut lips. Only small quantities of snow should be consumed in this manner because consumption of large quantities will reduce the body temperature.

Seawater is vastly different in its characteristics (as well as in the methods of purification used) from other surface sources. The chemical characteristics of seawater are such that normal coagulation and filtration are ineffective as treatment processes.

In developing seawater sources, consideration must be given to such factors as surf action, saltwater corrosion, suspended sand and silt in the water, living organisms, surface oil along beaches, and the rise and fall of the water level with the tides. If the equipment is located on sheltered bays, harbors, lagoons, or estuaries, it can be supplied by intakes built in the same way as freshwater surface intakes. On small islands where there is insufficient surface and ground water, and on or near open beaches, intakes for equipment can be built as follows:

1. Saltwater wells. Beach wells should, if possible, be used in preference to offshore intakes. Wells can be dug to tap fresh or salty ground water. This eliminates the problems caused by tides, surf, and shallow water close to shore. Such wells have an added advantage in that they can be built back of the shoreline under natural overhead concealment. Driven and jetted wells may also be used effectively at beach locations.

2. <u>Offshore intakes.</u> Offshore intakes are sometimes required because of lack of time, personnel, or equipment or because of coral conditions that prohibit well construction. Intakes of either the rigid pipe or float type may be used but they should be located in deep water beyond the surf. They must be positioned vertically and be off the bottom but still beneath the water surface at low tide. In this way foreign materials in the water which might cause excessive wear on equipment will be largely excluded. The rigid pipe intake can be placed on timber supports and anchored securely in position by piling or riprap. Floats securely anchored can support the intake screen in much the same manner as in surface waters. A rubber suction hose can be used to connect the rigid pipe on the sea bottom to the pipe supported beneath the float.

WATER CONTAMINATION

Water takes on various characteristics and properties as it passes over and through the earth. These characteristics and properties vary and are dependent on the materials encountered. These materials may be natural or man-made and are classified according to their means of detection.

● Physical—detected by one or more of the human senses

● Chemical—detected by chemical analysis

● Biological—detected by testing for chloroform organisms

● Radiological—detected by radiac equipment and special laboratory field tests

PHYSICAL IMPURITIES

Physical impurities in water are either suspended or dissolved. The suspended impurities are usually more dangerous to health. They include mineral matter, disease organisms, silt, bacteria, and algae. They must be destroyed or removed from water that is to be consumed by humans.

The most important physical characteristics are turbidity, color, odor, taste, and temperature. Valuable information can be obtained by observing the water with any of the five human senses and using commonsense judgment on the following characteristics:

● Color

● Turbidity

● Odor

● Taste (use with caution)

● Temperature

● Condition of vegetation around source (dead or mottled vegetation can indicate the presence of chemical agents)

● Presence of dead fish, frogs, and so forth

Before starting any treatment to remove color, turbidity, taste, or odor, you should take several preventive measures.

You must prevent the formation of algae in raw water supply points. Algae can be controlled with copper sulfate, chlorine, or activated carbon. Before deciding which method or combination of methods maybe most effective, consider the following factors:

● Volume of water to be treated

● Time of year

● The effects of treatment on fish life

● Type of secondary water treatment in use

● Equipment available

● Cost of treatment

You must also prevent the raw water source from becoming polluted by drainage from industrial waste and surface drainage from farms, mines, and watersheds.

The above conditions usually cause water to take on color due to the presence of colored substances in solution, such as vegetable matter dissolved from roots and leaves. Dissolved humus, iron, and salts could also be included. <u>True color</u> is due to substances in true solution, <u>apparent color</u> includes true color and substances suspension rather than dissolved. Color may also be caused by industrial wastes and turbidity. Color as such is harmless, but objectionable

because of its appearance and the taste and odors sometimes associated with it.

Turbidity is a muddy or unclear condition of water caused by particles of sand, clay, or organic matter being held in suspension. Clay and silt remain suspended in water for the longest period of time because of their particle size and specific gravities. The removal of turbidity is essential to the production of potable water. Removal reduces water contamination, extends the time between backwashing of filters, decreases chlorine demand, improves disinfection, and enhances user acceptability of the finished water. Proper water treatment requires turbidity removal because suspended particles often contain organisms that may cause diseases.

Turbidity is removed by coagulation and sedimentation. Since the physical characteristics of raw water vary widely in different locations, dosages of coagulant chemicals must be determined at each water point to ensure maximum efficiency with minimal waste of chemicals. After coagulation and settling, the water should not have more than 20 percent of the original turbidity. Daily jar tests will help check the optimum chemical dosage required to meet this standard.

COAGULATING CHEMICALS

The type of chemicals that should be used for coagulating raw water can be determined by using the results from jar tests, plant tests, or by using the data shown in table 9-3(A). Theoretically table 9-3(A) is correct; however, these values can be misleading when applied to some types of raw water. The chemical content of water may have a considerable influence on the optimum pH range for the various coagulants. For example, coagulation with ferrous sulfate is usually best accomplished at relatively high pH values in the alkaline zone. With soil, colored waters, ferric coagulant

may sometimes be used with considerable success at pH values of 4.0 or less. Because of this wide variation in the optimum pH range of coagulant (caused by individual characteristics of the raw water), the coagulant dosage and the optimum zone for floc formation should be determined by jar tests, rather than just relying on table 9-3(A).

Table 9-3(A).—Optimum pH Ranges for Common Coagulant

COAGULANT	pH
Aluminum sulfate	5.0 to 7.0
Ferrous sulfate	9.5 and above
Chlorinated copperas	4.0 to 6.5 and above 9.5
Ferric chloride	4.0 to 6.5 and above 9.5
Ferric sulfate	4.0 to 10.0

JAR TEST

The jar test is the most common method of determining proper coagulant dosages. When there is a question as to which chemical should be used as a coagulant, it is often necessary to run more than one series of jar tests. Different coagulant chemicals and pH ranges should be used to determine which one produces the most satisfactory results at the lowest cost. The step-by-step procedures for ajar test are as follows:

1. Prepare a standard solution of each

coagulant selected for trial by adding 10 grams of coagulant to 1 liter of distilled water.

2. Correct the pH of a sample of raw water to within the optimum range for the coagulant being tested (only if the pH is to be adjusted to the same extent in actual plant operation). Divide the raw water into six 1 liter samples,

3. Add 0.5 ml of standard coagulant solution to one sample of raw water, 1.0 ml to the second sample, 2.0 ml to the third sample, 3.0 ml to the fourth sample, 4.0 ml to the fifth sample, and 5.0 ml to the sixth sample. The result is a dosage of 5, 10, 20, 30, 40, and 50 mg/1, respectively.

4. Agitate samples in the jar test apparatus at a velocity about equal to the treatment equipment you are using and for the same length of time as the treatment equipment mixing time.

5. Keep the samples at the same temperature as water passing through your treatment equipment.

6. After stirring, let the samples settle for 30 minutes.

7. Siphon off a sample of the supematant and determine the turbidity by using a turbidimeter.

8. The smallest amount of coagulant that produces the lowest turbidity represents the optimum dosage. Multiply the coagulant dosage in mg/1 (step 5 above) by 8.33 to get the correct chemical feed in pounds per million gallons.

9. Repeat the steps for each chemical used until satisfactory results are obtained.

As to acceptability, the taste and odor of water must be considered from the user's point of view. Tastes and odors of water are most commonly caused by algae, decomposing organic material, dissolved gases, or industrial wastes. Potability is not fleeted by the presence of odors and tastes. On the other hand, palatability is frequently affected, particularly when a substance such as bone or fish oil is present. Tastes and odors that make water unpalatable must be removed. Use of free available chlorine, aeration, and activated carbon can do much to prevent or remove unacceptable tastes and odors from treated water.

The use of free available chlorine is advantageous because most odors and tastes are removed and rigorous disinfection is assured.

Activated carbon is the most widely used single process for taste and odor removal. Aeration and copper sulfate treatment are also used. All three methods are described below. The method used depends upon the substance or substances to be removed and the equipment available.

● Activated carbon is an excellent absorbing agent to use in ridding water of unpleasant tastes and odors. It is also an effective agent for removal of organic color. It is insoluble and tends to float unless all particles are wetted thoroughly by being made into a slurry before being added to the water. When continuous flow equipment is being used, the activated carbon should be added to the limestone feeder and added to the water with the limestone slurry. When the batch type of equipment is being used, the activated carbon can be added along with other chemicals in the coagulation tank. Being

insoluble, activated carbon does not affect the pH value or chemical characteristics of water. One ounce of activated carbon per 1,000 gallons of water is usually adequate. However, dosages up to 1 pound per 1,000 gallons can be used, depending upon the kind and degree of impurities present. Use of activated carbon in much higher dosages for removal of chemical agents is discussed later in this chapter.

NOTE: Treatment with activated carbon should always be made ahead of, or part of, the coagulation process, so the activated carbon and the various impurities absorbed by it are removed.

● Aeration treatment consists of adding oxygen by exposing the water to air. The process has a two-fold action. Volatile odor-producing materials are released to the atmosphere, and the action of the air upon readily oxidizable materials causes a precipitation of insoluble oxides and hydroxides. Removal of hydrogen sulfide is an example of the formal action, while removal of iron is an example of the latter action. The aeration of water to rid it of the taste and odor of decomposing vegetable matter generally involves both actions.

● Copper sulfate controls tastes and odors caused by small living organisms. This treatment is most frequently used in lakes and reservoirs. The copper sulfate is applied by towing a porous sack containing copper sulfate crystals behind a boat or by spraying a copper sulfate solution over the surface of the water. The amount of copper sulfate you should use depends on the type and concentration of organisms present. Dosages must be controlled because amounts greater than

2.0 parts per million (ppm) kill fish in the water. The amount necessary to remove microorganisms has no detrimental effect on human beings. Copper sulfate treatment is rarely used in field water supply for several reasons.

1. The advantage to be derived from treating an entire lake or reservoir frequently does not warrant the expense of the treatment when the length of time the water source is to be used is taken into consideration.

2. The amount of copper sulfate used entails considerations of wildlife, medical effects, and total water chemistry which are beyond the water supply technician's area of operation.

3. Superchlorination and dechlorination with activated carbon are effective for short periods although they are expensive for extended operations,

Temperature must be considered in the treatment of water. Lowering the temperature of water suppresses odors and tastes and, therefore, increases its palatability. In the summer, the temperature of deep lakes and reservoirs decreases sharply from top to bottom. By shifting the depth of intake, it maybe possible to draw relatively cool water even during hot weather. Water should be drawn from the lower depths when possible. Cool water is more viscous than warm water and thus is more difficult to filter. Cool water is more difficult to coagulate and chlorinate effectively than warm water because of slower reactions. Water treatment rates

should be reduced when water temperatures are less than 45°F.

CHEMICAL CHARACTERISTICS OF WATER

The most important chemical characteristics of water are its **acidity, alkalinity, hardness, and corrosiveness.** Chemical impurities can be either natural, man-made (industrial), or be deployed in raw water sources by enemy forces.

Some chemical impurities cause water to behave as either an acid or a base. Since either condition has an important bearing on the water treatment process, the pH value must be determined. Generally the pH influences the corrosiveness of the water, chemical dosages necessary for proper disinfection, and the ability to detect contaminants.

Hardness

Hardness is caused by the soluble salts of calcium, magnesium, iron, manganese, sodium, sulfates, chlorides, and nitrates. The degree of hardness depends on the type and amount of impurities present in the water. Hardness also depends on the amount of carbon dioxide in solution. Carbon dioxide influences the volubility of the impurities that cause hardness.

The hardness caused by carbonates and bicarbonates is called *carbonate hardness.* The hardness caused by all others (chlorides, sulfates, nitrates) is called *noncarbonated hardness.*

Alkalinity is usually equivalent to the carbonate hardness. Sodium, however, also causes alkalinity. In natural waters, sodium is not normally present in appreciable amounts.

Therefore, in natural waters, the alkalinity is equal to the carbonate hardness. After water has been softened, a large amount of sodium remains in the treated water. In softened water, the total alkalinity is the sum of the carbonate alkalinity plus the sodium alkalinity. Hardness is undesirable in that it consumes soap, makes water less satisfactory for cooking, and produces scale in boilers and distillation units.

The following minerals cause hardness in ground and surface waters:

● Calcium carbonate. Alkaline and only lightly soluble; causes carbonate hardness and alkalinity in water.

● Calcium bicarbonate. Contributes to the alkalinity and carbonate hardness of water. Calcium bicarbonate when heated produces carbon dioxide and calcium carbonate. This calcium carbonate precipitates as scale ib boilers and distillation units.

● Calcium sulfate or gypsum. Causes noncarbonated hardness in water. Being more soluble in cold water than in hot, it separates from the water in boilers and forms scale on the boiler tubes.

● Calcium cloride. Causes noncarbonated hardness in water. In steam boilers and distillation units, the presence of calcium chloride causes chemical reactions that can pit metallic tubing.

● Magnesium carbonate (magnesite) and magnesium bicarbonate. Act the same in water as calcium carbonate and bicarbonate.

● Magnesium sulfate (epsom salts). Adds to the noncarbonated hardness of water and causes boiler scale. In amounts greater than 500 parts per million in drinking water, it acts as a laxative.

● Magnesium chloride. Has the same properties and effects as calcium chloride. However, the magnesium will contribute to the formation of magnesium hydroxide scale on boilers and evaporators.

● Iron. Iron is undesirable because it imparts a rusty color and objectionable taste to water. It also forms crusts in plumbing and piping. When iron is present in water, organisms whose life processes depend on iron compounds may also be present. These organisms may cause tastes and odors and create what is called *red water.*

● Manganese. While not encountered as often as iron, it is found in both surface and ground water. Its presence in water normally causes a grey or black color. The total concentrations of iron and manganese in potable water should not exceed 0.3 ppm.

Iron and manganese removal is not normally required in the production of field drinking water. Oxidation by aeration, followed by sedimentation and filtration, is the most common method of removing iron and manganese. They are oxidized to insoluble ferric oxide and manganese oxide by this process. The same methods may generally be used to remove both iron and manganese, although when they are present together in water, removal is more difficult. Combinations of iron and manganese with organic matter may require aeration in trickling beds containing coke, followed by sedimentation and filtration. In some cases superchlorination followed by sedimentation and filtration will in itself remove these two substances. The addition of lime, Ca(OH)2, followed by sedimentation and filtration, is another method for removal of these substances.

The concentration of chemical substances present in water for military water supply should not exceed the values shown below. If local conditions or short-term requirements make the use of water containing higher chemical concentrations necessary, authorization must be obtained from the medical officer.

Chemical Substances	Maximum	Values
Copper	1.0	ppm
Iron	0.3	ppm
Manganese	0.05	ppm
Zinc	5.0	ppm
Magnesium	125.0	ppm
Chlorides	250.0	ppm
Sulfates	250.0	ppm
Phenolic compounds	0.001	ppm
Lead	0.05	ppm
Hexavalent Chromium	0.05	ppm
Fluoride	1.5	ppm
Turbidity (silica scale)	5.0	units
Color (platinum-cobalt scale)	15.0	units
Nitrate-Nitrogen	10.0	ppm
Total solids	500.0	ppm

Water softening is the term used to identify the process of treating water supply hardness. Water softening is most likely to be necessary when water is being supplied to laundries and heating units involving boilers and steam equipment.

● Lime-Soda Process. Lime-soda ash softening consists of the application of these materials to the raw water. Lime, Ca(OH)2, reacts with the soluble calcium and magnesium bicarbonates and forms insoluble calcium carbonate and magnesium hydroxide. Soda ash, Na2CO3, reacts with the soluble noncarbonated compounds of calcium and magnesium to precipitate insoluble calcium and magnesium compounds but leaves sodium compounds in solution. The physical operation of adding lime-soda ash and removing the precipitates is similar to that in the conventional coagulation-filtration process for bacteria and turbidity removal.

● Zeolite Process. Zeolites used in water softening are complex compounds of sodium, aluminum, and silica which have the faculty of exchanging bases. They are often called *green sand* because of the color of natural zeolite. Synthetic zeolites are also available. When water

containing calcium and manganese compounds passes over the zeolite, the calcium and manganese are exchanged for the sodium in the zeolite. In this way the water is softened and its sodium content increased. When the sodium of the zeolite is exhausted, it is regenerated by applying a sodium chloride solution. Another exchange is made, and the resulting concentrated solution of calcium and magnesium chloride is discharged to waste. The operating rate varies directly with the thickness of the zeolite bed. The time between regenerations depends on the characteristics of the water and the total amount of water applied. The need for regeneration will be evident when hardness is no longer removed. The zeolite process can only be used on water that has been treated for removal of turbidity.

● Ion Exchange. The ion exchange unit, when run on the sodium cycle, will significantly soften water. The ion exchange unit will also remove such undesirable ions as (hose of manganese and lead.

Dissolved Gases

The concentration of a gas in water is directly proportional to the concentration, or partial pressure, of the gas in the atmosphere in contact with the water surface. In general, this involves the water temperature, its salinity, and the altitude. The gases of primary interest to water supply are as follows:

● Oxygen. Large amounts of dissolved oxygen are found in rainwater. The amounts in surface water vary greatly, depending on the amount and type of pollution, the degree of self-purification, the action of algae, and the temperature of the water. Polluted water will exhaust the oxygen supply, while clean water will contain much dissolved oxygen. Cold water contains larger amounts of dissolved oxygen than warm; as water temperature rises, the dissolved oxygen is released to the atmosphere. Decreased pressure on water has the same effect, releasing oxygen to the atmosphere. Dissolved oxygen causes the solution of metals and, especially in the presence of carbon dioxide, causes many metals to corrode.

● Carbon Dioxide. The presence of carbon dioxide in water contributes to the degree of

hardness and acidity of the water. Water acquires this gas in four ways: from the air by natural movements of water in contact with the air, such as currents and wave action; by contact with decomposing vegetation, which gives off carbon dioxide freely; by the reaction of ferric chloride and limestone in the coagulation process; and by contact with the gas in underground deposits. A high carbon dioxide content usually makes water more corrosive to metals.

● Hydrogen Sulfide. Hydrogen sulfide in solution lends a disagreeable taste and rotten-egg odor to water. Ground water absorbs sulfides by passing over sulfur-bearing rocks. Hydrogen sulfide is also responsible for the destruction of cement and concrete as well as the corrosion of metals. In small amounts, it is unpleasant but not dangerous. In large amounts it is harmful. Water that smells of hydrogen sulfide should be treated.

Dissolved gases are removed by means of aeration or the use of activated carbon. Aeration exposes as much water as possible to the air. This will release dissolved gases such as hydrogen sulfide and carbon dioxide to the atmosphere. Liberating the dissolved gas from the water by aeration permits the oxygen in the air to come in contact with the finely divided water particles, thereby increasing the dissolved oxygen content of the water. This increase of oxygen content removes the offensive taste and odor imparted by the dissolved gases. Aeration raises the pH by eliminating the carbon dioxide, but increases corrosiveness by increasing the amount of dissolved oxygen. One type of aerator consists of trays containing slats or coke over which the water is sprayed. Other methods of aeration include spraying water up over a shallow receiving basin and forcing air into a basin with diffusers or mechanical pump-type aerators similar to those used in sewage treatment. Operation of most aerators is practically automatic; operators' duties consist essentially of making sure pipes, slots, and surfaces are not clogged and that air has free access to the water. If the water is not to be filtered after aeration, aerators must be screened to keep out insects and other foreign matter.

Activated carbon is a specially treated granular powdered carbon. It absorbs or attracts large quantities of dissolved gases. It is extremely

effective in taste and odor control, provided the

1. type of activated carbon used meets minimum standards,

2. dosage is correct,

3. carbon is mixed intimately with the water, and

4. carbon is in contact with the water for an adequate period.

Acceptable commercial preparations of activated carbon should meet the following minimum specifications:

1. It does not contain any soluble mineral injurious to health.

2. Moisture content is not over 8.0 percent.

3. It is powdered form that wets down and goes into suspension readily, does not settle too rapidly, and does not float on the surface when applied.

4. At least 99 percent of the carbon in water suspension passes a 100-mesh sieve and 95 percent passes a 200-mesh sieve.

5. It has enough adsorption capacity to reduce a concentration of 0.1 milligrams per liter (mg/l) phenol in distilled water to 0.01 ppm.

Because of the wide range in waters, no general rule can be given for activated-carbon dosage. The dose required at each water plant must be determined by periodic laboratory tests. The test is made by preparing a number of samples of raw water, adding the standard amount of treating chemicals and varying amounts of carbon to each sample, allowing plant contact time, filtering, and making odor tests. Numerical comparison can be made with the threshold odor test. A carbon dose of 3 ppm removes most tastes and odors from water. However, dosages can vary from 3 to 15 ppm, depending upon the odor of the water. Laboratory tests will determine the dosage.

Activated carbon is fed into the water by dry feeders. It must be handled more carefully than coagulant because it is a fine powder; therefore, the feeder must bean approved type and designed to prevent the spreading of the carbon dust and causing fires. In addition, inhaling of the dust by personnel, even in low concentration, can affect their lungs. The dry feeder room should have explosion proof electrical equipment. A spark or pilot flame can create an explosion. Dry carbon will float on the surface of the water for a long time. Therefore, it is important that the carbon be wetted thoroughly, mixed by agitation using a paddle wheel, swirling action, a spray, or so forth, in a small tank. Some dry feeders have a mixing chamber in which the carbon is wetted by the swirling action of the water.

Activated carbon may be applied to the water at one or several points, depending on the results desired. Carbon is added at one or more of the following points:

● In the raw water, as early as possible after it enters the plant. This point of application is not recommended for extremely turbid waters.

● In the mixing basin. When added before sedimentation, activated carbon not only removes foreign matter from the water, but the carbon that settles in the sedimentation basin continues to absorb products of sludge decomposition, thus preventing formation of secondary tastes and odors. Black alum is premixed activated carbon and coagulant that can be used in special situations both as a coagulant and for taste and odor control.

CHEMICAL, BIOLOGICAL, AND RADIOLOGICAL (CBR) CONTAMINATION

Should chemical or biological agents or nuclear weapons be employed during conflicts, the water supply of the area involved would, in all likelihood, become contaminated. A water source contaminated with a chemical, biological, or radiological agent can cause incapacitation or death to a consumer. Effective means for determining the presence of CBR agents, followed by proper decontamination procedures, can reduce or eliminate the hazards caused by these agents.

In the event that you are assigned to supervise or manage a field water supply point, you will be responsible for the detection and removal of CBR contaminants. The supervisor of a water point crew must be sure the crew is trained in the identification of CBR contamination by

recognizing the various indications of CBR contamination of their water point as follows:

- An unusual taste or odor
- Dead fish and animals in unusually large numbers
- A sudden drop in normal pH values or a pH value of less than 6.0
- High readings on radiac equipment
- Personnel developing fevers, diarrhea, cramps, vomiting, and so forth
- Burning sensation of skin, eyes, and nose
- Runny eyes, nose, and mouth

If CBR contamination of a water source is suspected, have your crew don appropriate protective clothing and equipment before they start tests for determining the type and extent of the problem. For example, water contaminated with a nerve agent should not be allowed to come in contact with the skin nor the vapors be inhaled. Therefore, wearing a protective mask and gloves would be necessary before checking for nerve agent contamination.

Chemical Contamination

Chemical agents are classified in seven categories: nerve, blister, blood, choking, vomiting, irritant, and incapacitating. The nerve agents, blister agents, and agents containing cyanide are most dangerous because they are highly poisonous. Some are soluble in water and either are slow to decompose in solution or remain poisonous after decomposition. Water supplies are likely to become contaminated as an incidental result of widespread chemical attack, rather than as a result of direct attack on the water supply. Chemical agents are colorless, odorless, and tasteless. The first indication of their use could be the appearance of casualties. The chemicals affect people, animals, and plants but leave homes, factories, and other facilities untouched.

Biological Contamination

Water is a carrier of many organisms that cause intestinal disease. An epidemic of one of these diseases among troops can be more devastating than enemy action and can cause great damage to morale as well as health. A heavy responsibility thus rests upon the Utilitiesman, and vigilance over water purification equipment and procedures should never be relaxed. It is emphasized that water treatment methods to be used when certain chlorine-resistant organisms are encountered should be prescribed by a representative of the medical officer. The representative will recognize or anticipate the presence of these organisms and recommend such additional chlorination or other treatment methods as may be necessary.

A waterborne disease rarely produces symptoms in its victim immediately after the victim has consumed the contaminated water. A period of time, known as the incubation period, must pass before the victim comes down with the disease. During this incubation period, the disease organisms are growing and multiplying. Absence of symptoms for several days after untreated water has been consumed is, therefore, no guarantee that the water is safe. Also, absence of disease among the local inhabitants is no assurance of safety because they may have developed immunity.

Types of waterborne diseases include typhoid fever, paratyphoid fever, cholera, bacillary dysentery, amebic dysentery, common diarrhea, infectious hepatitis, and schistosomiasis. Biological water contamination causes little, if any, change in

the chemical and physical characteristics of water, such as pH, alkalinity, and color. This makes it difficult to test a water source for contamination. However, when the water has an excessive chlorine demand, it should be viewed with concern. The excessive demand could be due to microorganisms. Other indicators are as follows: aircraft dropping or spraying of unidentified material; unusual types of bombs, particularly one which bursts with little or no blast; smoke and mist of an unknown substance: unusual increase in insects, such as mosquitoes, ticks, or fleas; increased occurrence of sick or dead animals; increased incidents of troop sickness and disease; or intelligence reports indicating enemy use of a biological contaminant.

Radiological Contamination

Although nuclear weapons have been used in combat, there are no reliable data as to the effect of nuclear explosions on field water supplies. However, available fallout data leave no doubt that contamination of water supplies by this means must be considered. Since radiation is not detectable by human senses, you should use instruments and laboratory tests to determine its presence.

A nuclear attack over or near a source of water supply will probably cause its contamination with radioactive materials. A nuclear explosion could cause contamination by any of the following (listed in the decreasing order of importance to the water point operator):

● Fallout of fission products

● Induced activity in the water and surrounding soil

● Blow-in or wash-in of radioactive dust

● Fallout of unfissioned uranium or plutonium

The magnitude of contamination depends upon the yield of the weapon, the location of the detonation with respect to the water source, and whether it is air, surface, or subsurface burst.

TREATMENT OF CBR CONTAMINATION

If chemical, biological, or radiological agents, or any combination of these, are used, the field water supply will inevitably be involved. It is impossible to foresee what type of agent will be used, but effective security measures can decrease and counteract the hazards of all three types of agents.

Effective security involves prompt and accurate detection. Contamination by chemical agents usually, although not always, leaves significant signs that should arouse immediate suspicion. These are drastic lowering of the pH value of the water, characteristic odors and tastes, and dead fish. If chemical contamination is suspected, the medical officer will have medical personnel test the water with the Chemical Agent Water Testing Kit M272. A complete technical and operational breakdown of this kit can be found in Army TM-3-6665-319-10.

Advice and guidance from the medical officer must be sought and followed carefully when water contaminated by CBR agents must be treated and used. Specialized training of personnel in the latest means of detection and treatment will aid water supply technicians in safeguarding the lives and health of personnel.

If contamination of any type, by CBR

agents or poisonous industrial wastes, is detected, every effort must be made to find an uncontaminated water source before considering treating and using water known to be contaminated.

When an uncontaminated source of supply is not available for use, permission must be secured from proper medical authority to proceed with treatment of the contaminated water.

Water is considered CONTAMINATED AND UNSAFE for treating if one or more of the following results are obtained from competent testing:

Arsenic test. . . . . positive
Mustard test . . . . positive
pH test . . . . .pH below 6
Chlorine demand test . . . . positive
Nerve agent test . . . . positive
Taste and odor test . . . . positive

Water is considered safe for treatment by the usual methods if the pH is above 6.0 and all other contamination tests are negative.

When contamination by a CBR (chemical, biological, radiological) agent has been determined to be present in your water source, the Reverse Osmosis Water Purification Unit (ROWPU) may be used.

The ROWPU will successfully remove 99 percent of CBR contamination from a water source. A post-treatment system in conjunction with the ROWPU will remove a total of 99.9 percent of CBR contamination.

Post Treatment

The 600-gph ROWPU post-treatment system consists of two CBR cylinders. One cylinder is for nuclear and the other is for chemical. The types of contamination present will determine what cylinder you should use. The CBR cylinder filters are capable of decontaminating water for up to 100 operating hours. The cylinder marked "nuclear" contains resin beads that absorb certain ions present on the nuclear battlefield. The cylinder marked "chemical" contains activated carbon that absorbs agents found on the chemical battlefield.

Nuclear Agent Removal

The ROWPU removes the majority of ions wit bout post treatment. The reverse osmosis (RO) removal characteristics for nuclear warfare agents are as follows:

● 95.5% of iodine, leaving the nuclear cylinder to remove 4.5%.

● 99.7% of strontium, leaving the nuclear cylinder to remove .2%

● 98.% of cesium, leaving the nuclear cylinder to remove 1.2%.

Chemical Agent Removal

The ROWPU also removes large amounts of chemical agents. RO removal characteristics for various chemical warfare agents are as follows:

● GB-99.1%, leaving the chemical cylinder to remove .7%.

● VX-99.9%, leaving the chemical cylinder to remove .1%.

● BZ-99.9%, leaving the chemical cylinder to remove .1%.

● GD-99.7%, leaving the chemical cylinder to remove .3%.

Biological Agent Removal

The ROWPU also removes biological agents from a water source. Reverse osmosis removal characteristics for various chemical agents do not exist. Any biological agent that is not removed by the ROWPU will be eliminated by the chlorine residual maintained in the product water.

WATER TREATMENT EQUIPMENT

The Utilitiesman may be called upon to select and set up various types of field water treatment equipment. You must be familiar with the theory of operation, the capabilities, the installation considerations, and the maintenance requirements of this equipment. This section covers four types of water treatment equipment. They are distillation, reverse osmosis, filtration, and disinfection units.

DISTILLATION

In areas where a satisfactory freshwater source cannot be located and existing water treatment facilities are not usable, the distillation process can be used to obtain fresh drinking water from brackish water, seawater, or water containing excessive amounts of dissolved solids. Distillation is effective for removing radioactive contaminants from water. Since the output of distillation equipment is limited and the process is expensive, its use is restricted to situations in which no other process is adequate. Continuous flow or batch type of water purification equipment is used whenever possible.

Theory of Operation

Distillation consists of heating water to form steam, separating the steam from the remaining water, and then cooling the steam so it becomes water again (fig. 9-12). As the water is heated to form steam or water vapor and the vapor is separated and then cooled, solids dissolved in the water do not vaporize but remain behind in the raw water. A large amount of heat that is not evidenced as a rise in temperature is required to change (vaporize) boiling water into steam. The process whereby latent heat is removed and steam becomes water is called *condensation.*
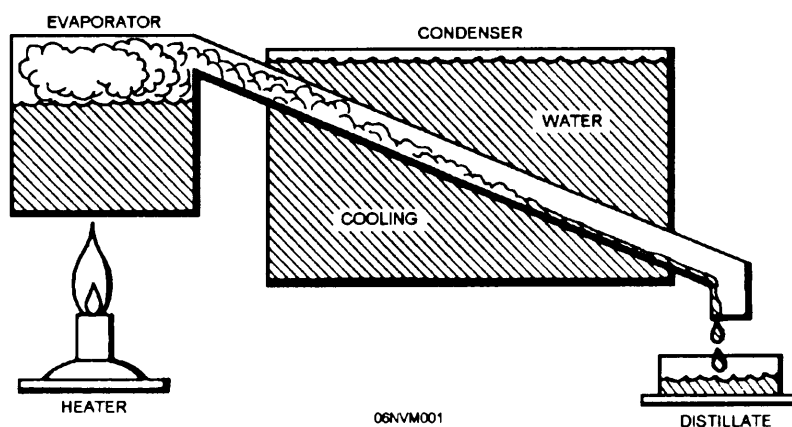

Figure 9-12.—Distillation in its simplest form.

Heat flows through the bottom of the evaporator, enters the water, and changes the water to steam. The steam is condensed in the condenser, its latent heat of vaporization being transferred to the water surrounding the tubes. A portion of the cooling water that has picked up heat in passing through the condenser is used as feedwater for the evaporator. All dissolved solids remain in the equipment and noncondensable gases are vented to the air so the resulting distillate is almost pure. Thus the distillation process is usefull in producing water of an extremely high purity and low in total solids,

Despite this high degree of purity, all distilled water must be disinfected before being consumed because of the possibility of recontamination during handling, In thermocompression distillation, the latent heat of vaporization of steam is again used to produce additional steam. The pressure and temperature of the steam generated in the evaporator are raised by compressing the steam. The compressed steam passes to the condenser section where it condenses, giving up its latent heat and causing more steam to form in the evaporator. This steam is then compressed and the cycle repeated. The use of combination evaporator-condenser with a steam compressor creates a closed heat cycle, permitting the continued reuse of the latent heat of vaporization. The compressor is driven by a gasoline or diesel water-cooled engine.

Figure 9-13 shows the operation of a simple thermocompression distillation unit. Cold raw water flows through heat exchangers where it is heated almost to boiling by the outgoing streams of distillate and brine and by water from the engine that drives the compressor. The hot raw water flows into the evaporator-condenser and is
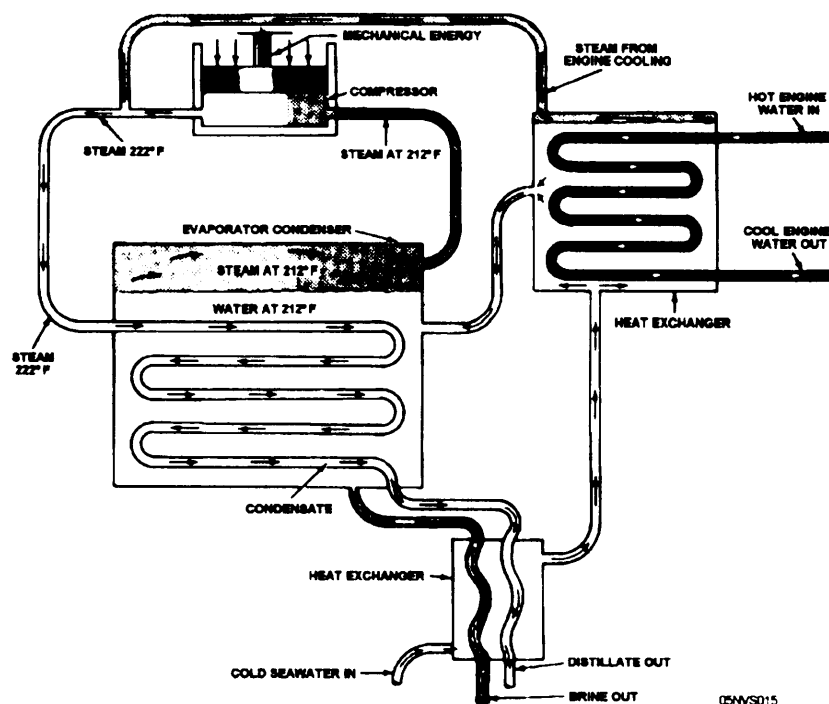

Figure 9-13.—Flow diagram-thermocompression distillation.

changed to steam by the steam condensing in the tubes. This involves the transfer of latent heat. The steam in the evaporator is drawn into the compressor where it is compressed and its temperature raised (from 212°F to 222°F). The compressed steam flows back through the coils in the evaporator-condenser where it transfers its latent heat through the walls of the coil into the water in the evaporator section. This transfer of latent heat causes the steam to condense in the coils and changes the water in the evaporator into steam. This cycle will continue as long as the compressor runs.

Installation

At permanent naval activities, the installation of distillation equipment will be designed by engineers and improvements to the system can be made over a long period of time. In the tactical field environment, it will be the Utilitiesman supervisor who must consider various factors for the installation of distillation equipment. These are as follows:

- potable water demand

- Site location

- Site drainage

- Security

- Fire protection

The demand for potable water will determine the number of distillation units, the need for storage facilities, operating hours, and so forth. You must determine the population you will be serving. Keep in mind that your water point may supply many units in an area, not just your organization.

The site location for distillation equipment must be upstream of any source of contamination. You must consider ocean currents that may change with wind direction, weather conditions, the season of the year, or tidal action. It is not efficient use of personnel or equipment if you have to relocate because the wind changed direction.

The site must also be relatively flat with a gradual slope toward the ocean. You also must allow for' maximum tidal action. In many areas the tide may rise and fall several feet, depending on the season of the year. Build low platforms to keep your equipment out of the sand and to allow air to circulate underneath tanks to prevent rot. These platforms also prevent punctures of the storage tanks by sharp objects and provide a stable working area for operating personnel.

The importance of providing adequate drainage at any water point cannot be overemphasized. Wastewater from filters, leakage from tanks, and spillage from distribution points can render a water point inoperable as well as creating an unsanitary condition.

Your water point may or may not be located in the vicinity of friendly forces. Denying the enemy information about your water point by using overhead concealment and camouflage may be necessary as well as guarding against ground attacks and sabotage with a defensive plan. Any adverse effect, from thirst to disease, the enemy can have on a water point will affect the well-being of the force using it. It will

be considered in the plans of the enemy.

Distillation equipment cannot produce water quickly enough to be used for fire protection. Do not permit your treated water to be used for this purpose except in extreme emergencies. Raw water should be used whenever possible.

REVERSE OSMOSIS

The use of reverse osmosis water purification equipment by the military has produced potable water from the sources available in a combat field environment. The reverse osmosis water purification unit (ROWPU) is capable of treating **freshwater, brackish water, and seawater.** Additionally, the unit is capable of treating water contaminated with **chemical, biological,** and **radiological warfare agents.** When using the unit to treat water contaminated by CBR agents, you must use the equipment in conjunction with auxiliary ion exchange and carbon adsorption units.

The ROWPU used by the NCF is capable of producing 600 gph of product water from freshwater sources and 400 gph of product water from seawater at 70°F. The rate of water production in the ROWPU depends upon the operating pressure, normally 350 to 550 psig for freshwater and 750 to 950 psig for seawater. Temperature affects the rate of flow. Cold water decreases the flow, while warm water increases the flow.

NOTE: Maximum operating water temperature of the ROWPU feedwater is 120°F. Water temperatures above this figure may damage the membranes within the reverse osmosis modules.

Reverse osmosis (RO) is a purification process in which **filtered water is** pumped against a semipermeable membrane under great pressure. The membrane allows product water to pass through while rejecting impurities, both dissolved and suspended. You must use an extremely high pressure for a usefull volume of water to pass through a unit membrane. The reverse osmosis process is shown in figure 9-13(A). Reverse osmosis may appear to be nothing more than a filtering process, but there are distinct differences. In filtration, the entire liquid stream flows through the porous filter medium and no chemical changes take place between the feed and the filtrate. In RO, the feed flows parallel to the semipermeable membrane with a fraction of it passing through a given membrane area; dissolved ionic and organic substances are rejected by the membrane and, in this case, drained off as a brine.
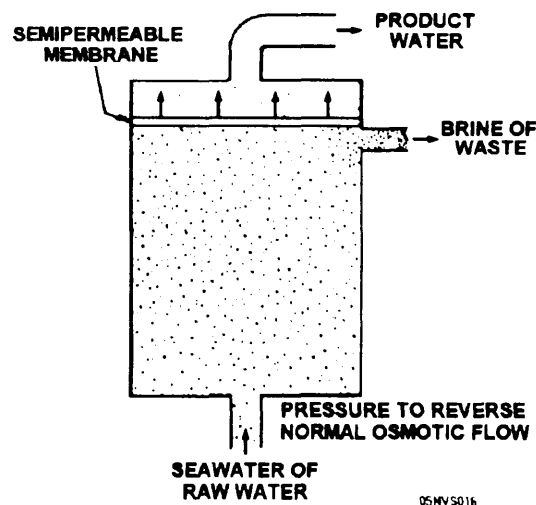

Figure 9-13(A).—Reverse osmosis process.

The following explanation is the flow process through the 600 gph ROWPU. As you read through this section, refer to the flow diagram in figure 9-13(B). Water is delivered to the ROWPU through the raw water pump. Upon entering the unit, it goes through the multimedia filter. This filter removes small and large solids. From the multimedia filter, the water is picked up by the booster pump that pushes the water through the cartridge filter. The cartridge filter takes out suspended solids that passed through the multimedia filter. From the cartridge filter, the water is picked up by the RO pump that pushes the water under high pressure through the pulse dampener and into the RO elements. The RO elements remove dissolved minerals and other bacteria that passed through the filters. The product water leaving the last element receives enough chlorine to kill any remaining bacteria.
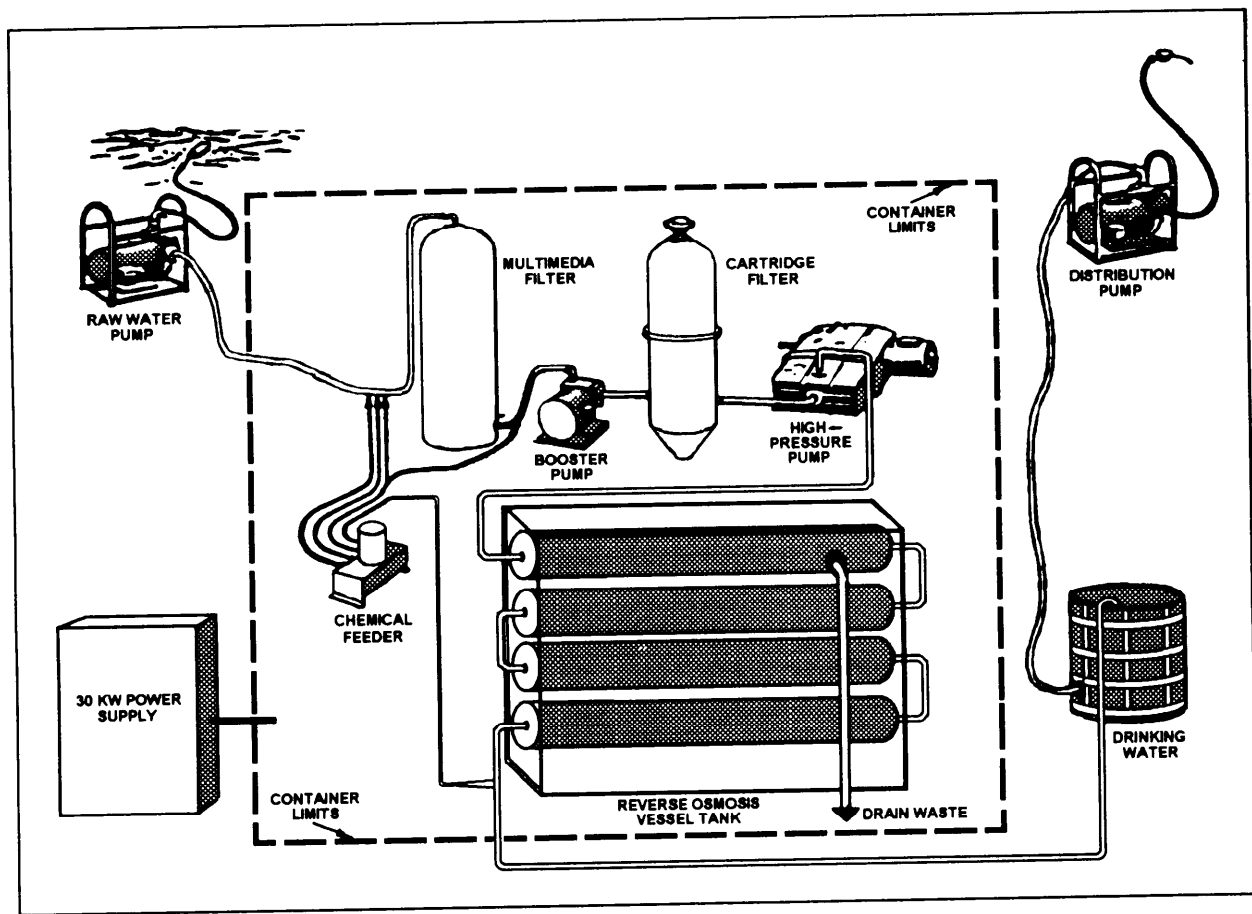

Figure 9-13(B).—Water flow through the 600 gph ROWPU.

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FILTRATION

Filtration consists of passing the water through some porous material to remove the suspended impurities. Filtration is one of the oldest and simplest procedures known to man for removing suspended matter from water and other fluids.

It is a common misconception that filtration removes suspended solids by a simple straining process whereby particles too large to pass through openings in the filter media are retained on the media. The mechanism involved in removing suspended solids by filtration is very complex. While straining is important at the filter media surface, most solid removal in deep granular filters occurs within the filter bed.

Flocculation and sedimentation in the pore spaces between filter media particles are an important removal mechanism as well as absorption of particles onto the filter media surfaces. Additional straining between media particles within the filter also contributes to overall solids removal.

The simplest form of water filter is the sand filter. This filter resembles a small reservoir, whose bottom is a bed of filter sand that rests on abed of well-graded aggregate with the largest size aggregate being at the bottom. An underdrain system of tile or brick is provided beneath the gravel to collect the water from the filter area. The underdrain system consists of a header or main conduit extending across the filter bed. Means are provided for regulating the flow of water out of the filter through this header and also for controlling the rate of flow onto the filter. This allows the filter to be operated at controlled rates that should not exceed 3.0 gph per square foot of filter area. An average filter bed consists of about 12 to 20 inches of gravel and 20 to 40 inches of sand, The depth of water over the sand bed varies from 3 to 5 feet.

The cartridge filter basically comes in two types of cartridge filtration: (1) depth filtration, where solid particles become trapped within the filter medium, and (2) surface filtration, where solid particles form a cake on the surface of the filter medium. Wound fiber cartridges function primarily as depth filters and are the standard cartridge used in the 600 gph ROWPU. (See cartridge filter in figure 9-13(C).) The most effective filtration system ever devised and one of the most effective portable systems in existence is the diatomite filter unit.
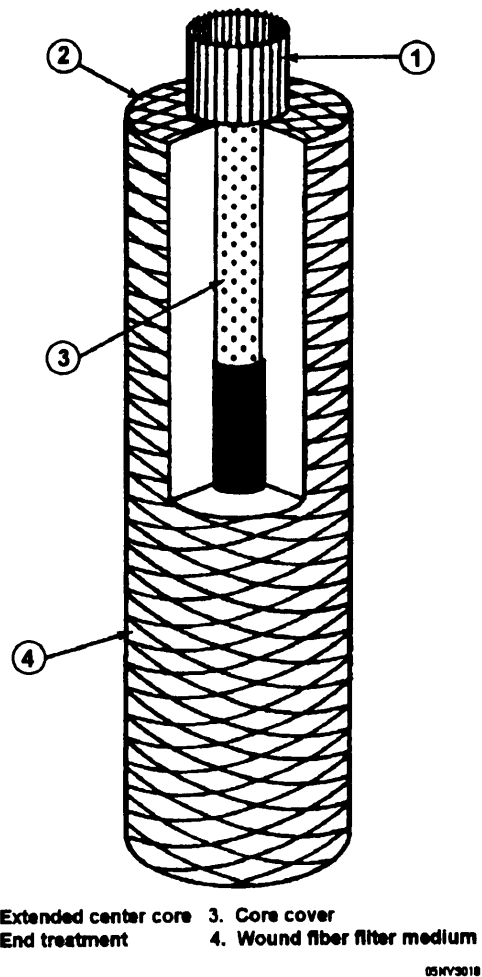

1. Extended center core 3. Core cover
2. End treatment 4. Wound fiber filter medium

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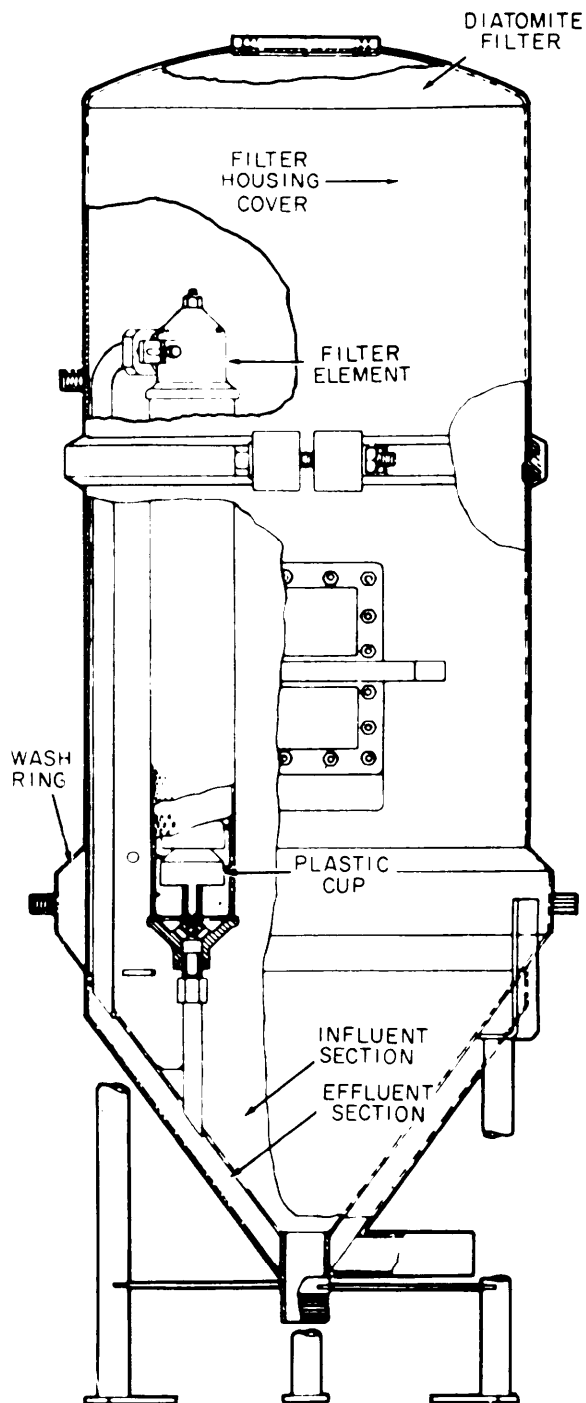**Figure 9-13(C).—Cartridge filter.**

(fig. 9-14). In the diatomite filter, water is passed through a layer of diatomaceous silica (also called diatomaceous earth). It consists of skeletal remains of minute algae (diatoms) found in marine deposits that have lifted above sea level.

The diatomite filter accomplishes highly efficient filtration. Properly operated diatomite filters are capable of removing from coagulated and settled water, amoebic cysts, the cercariae of schistosomes, and approximately 90 percent of the bacteria. They also produce water with less than one unit of turbidity.

Before filtering, water is normally pretreated by passing it through sedimentation basins or holding tanks. This process removes heavier suspended solids that may cause rapid clogging of the filter. This water is brought onto the filters as the next step in the purification process. This water contains very finely divided suspended matter such as minute particles of floc, clay, and mud that have not settled, and bacteria and microscopic organisms that have not been removed by sedimentation. The purpose of the filter is to remove this suspended matter and give the water a clear, sparkling, and attractive appearance.
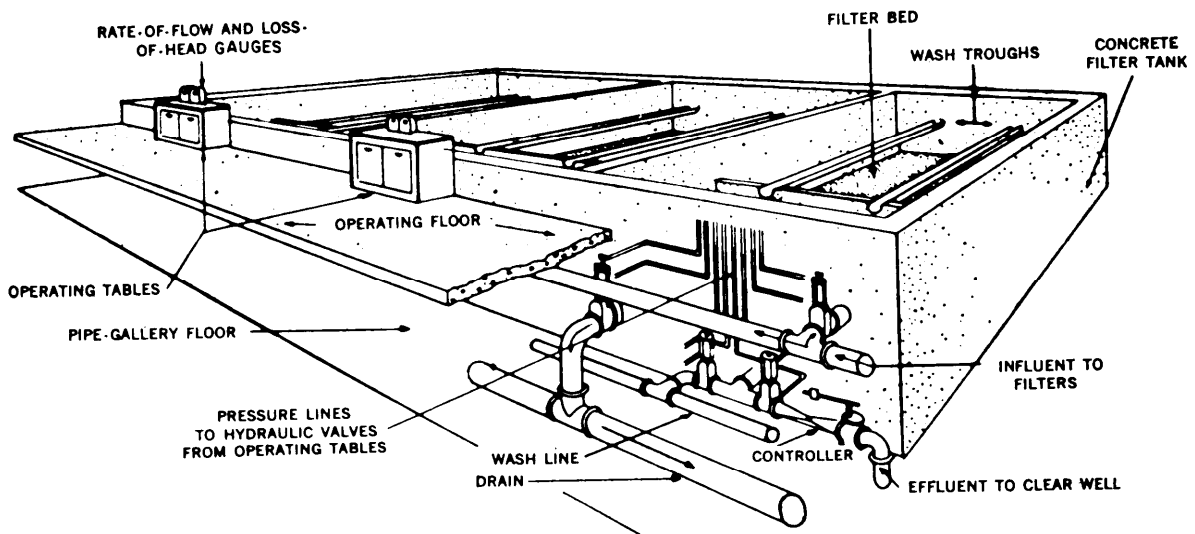
There are basically three types of filters. These are slow sand filters, rapid sand filters, and pressure filters.

Slow sand filters contain fine-grain sand and have low filtration rates. They are usually used when coagulation is not included in the treatment process. Their capacity is about 2 to 10 million gallons per day (mgd) per acre of filter surface. Use of slow sand filters has been practically discontinued because of their high cost per unit of capacity and the labor required to clean them. Rapid sand filters are now universally used in modern water treatment plants. There are two types, gravity and pressure. Gravity filters (fig. 9-1 5) are essentially open-top rectangular concrete boxes about 10 feet deep. An underdrain system at the bottom is covered by gravel, which, in turn, supports a 24- to 30-inch layer of fine filter sand (fig. 9-16). Gravity filters are usually designed to filter about 2 gpm per square foot of filter-bed area. However, in an emergency, up to 4 gpm per square foot can be obtained if prior treatment by flocculation and sedimentation produces very low turbidity and prechlorination and postchlorination or both are effectively disinfecting the water. Approval must be obtained from the major command to operate filters at rates in excess of 2 gpm
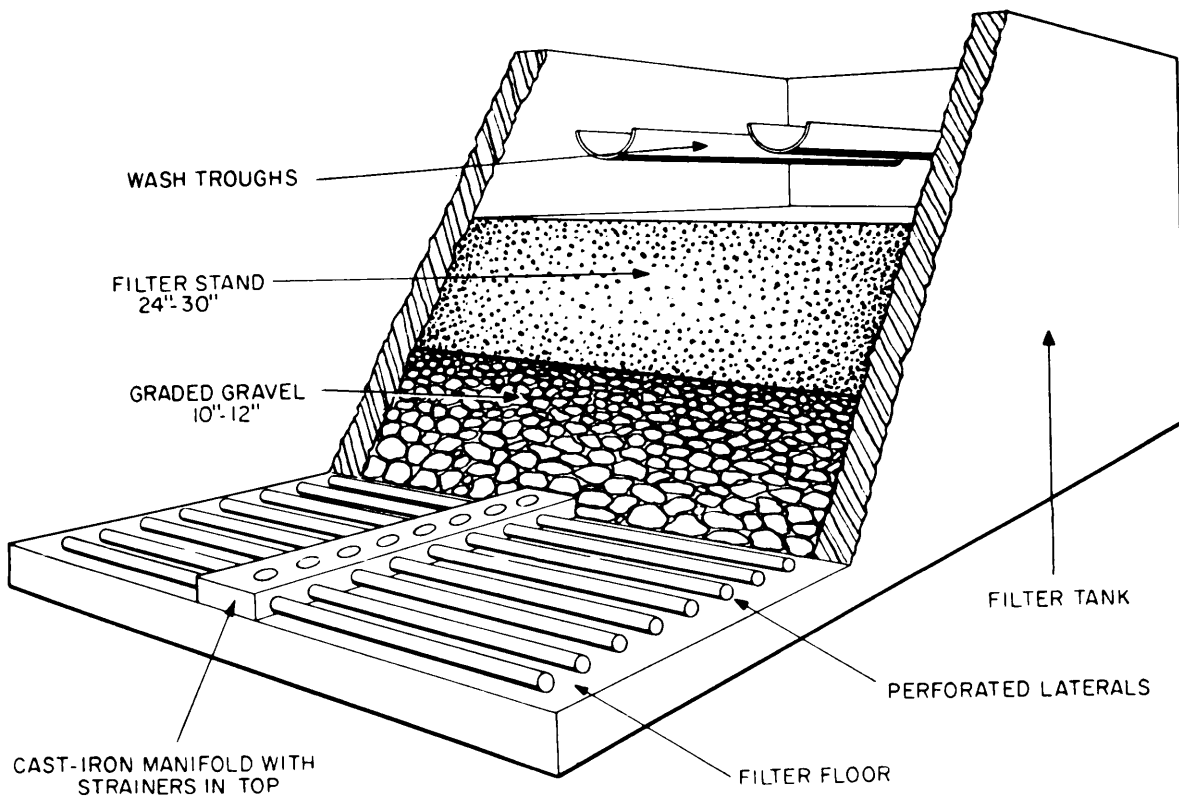

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Figure 9-14.—Diatomite filter, showing one filter element.

RATE-OF-FLOW AND LOSS-OF-HEAD GAUGES

FILTER BED

WASH TROUGHS

CONCRETE FILTER TANK

OPERATING FLOOR

OPERATING TABLES

PIPE-GALLERY FLOOR

INFLUENT TO FILTERS

PRESSURE LINES TO HYDRAULIC VALVES FROM OPERATING TABLES

WASH LINE

DRAIN

CONTROLLER

EFFLUENT TO CLEAR WELL

87.396

Figure 9-15.—Battery of three gravity-type rapid sand filters.

WASH TROUGHS

FILTER STAND 24"-30"

GRADED GRAVEL 10"-12"

CAST-IRON MANIFOLD WITH STRAINERS IN TOP

FILTER FLOOR

FILTER TANK

PERFORATED LATERALS

87.397

Figure 9-16.—Typical sand filter showing relationship of filter media.

9-29

per square foot. Pressure filters (fig. 9-17) have the filter bed enclosed in a pressure vessel. Water is either pumped into the vessel and forced through the filter or is drawn into the vessel and through the filter by a pump. The diatomite filter is classified as a pressure filter.

DISINFECTION

Besides coagulation, sedimentation, and filtration, water must undergo an additional treatment step; disinfection. This is necessary because no combination of the other three steps can be relied upon to remove all disease-producing organisms from water; also because there is danger of recontamination during handling before consumption. Residual disinfection using chlorination is the final step in all water treatment processes (including distillation). Under emergency or field conditions, water may be disinfected with iodine or by boiling.

The most satisfactory means of water disinfection and provision of a residual is by means of a chemical disinfectant. The efficiency of the disinfection process is dependent upon numerous

factors. These include the chemical used, the contact time, the type and concentration of microorganisms, the pH and temperature of the water, the presence of interfering substances, and the degree of protection afforded organisms from the disinfecting solution by materials in which they are imbedded. Therefore, various concentrations of disinfectant are required depending upon the local environmental conditions and the amount of particle removal effected.

Chlorine is the most commonly used chemical for disinfection of water. It is used in field water supply in the form of calcium hypochlorite, a standard item in the supply system (commercially known as HTH powder). When the calcium hypochlorite is dissolved, the chlorine goes into solution and a calcium carbonate sludge settles out. The chlorine is present in the solution as hypochlorous acid or hypochlorite ion (depending on the pH). Both forms are powerful oxidizing substances. The chlorine available in either form rapidly oxidizes the organic and inorganic matter, including the bacteria in the water. In this reaction the chlorine is converted to chloride and is no longer available as a disinfectant. The organic matter as well as such material as iron and manganese consumes the chlorine. The use of chlorine makes it possible to introduce an accurately measured dosage to ensure the destruction of disease-producing organisms and provide a readily measured residual to safeguard against recontamination during further handling.

Chlorine dosage is the amount of chlorine added to water to satisfy the chlorine demand as well as to provide a residual after a specified time. The amount required to disinfect water varies with the organic content and pH value of the water, the temperature, the time of contact, and the chlorine residual required. The dosage is usually stated in terms of parts per million (ppm) or milligrams per liter (mg/l).

The chlorine demand of water is the difference between the quantity of chlorine applied in water treatment and the total available residual chlorine present at the end of a specified contact period. The chlorine demand is dependent upon the nature and the quantity of chlorine-consuming agents present and the pH value and temperature of the water. (High pH and low temperatures retard disinfection by chlorination.) For comparative purposes, it is imperative that all test conditions be stated. The smallest amount of residual chlorine considered to be significant is 0.1 ppm. The relationship of the demand to the length of the contact period is discussed below.
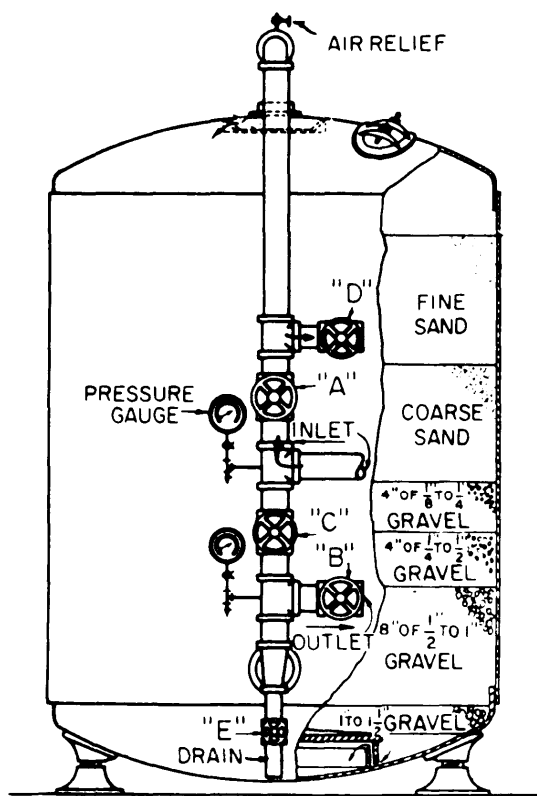
87.398

Figure 9-17.—Pressure filter.

Some of the chlorine-consuming agents in the water are nonpathogenic (nondisease-causing organisms), but this bears no relationship to the fact that they contribute to the total chlorine demand of the water. Navy policy requires that for field water supplies, the chlorine demand must be satisfied and chlorine residual must be present.

Residual chlorine is the amount of unreacted chlorine remaining at a specified time after the chlorine compound is added. Chlorine in aqueous solution is highly unstable. It may change quantitatively and qualitatively under numerous conditions, including the presence of other elements or compounds. The total residual chlorine in the water can be chemically divided into several types.

● Total available residual chlorine. This is the sum of the free available chlorine and the combined available chlorine.

● Free available chlorine. This refers to hypochlorous acid and hypochlorite ion present in water. These are the most effective disinfection forms of chlorine. The free available chlorine is a rapid-acting type, important because it can be relied upon to destroy bacteria relatively quickly, and thus is active during the period immediately following chlorination. The relative amount of each present in the water is dependent upon the pH value of the water. It is important to remember that when the pH is raised, the quantity of free available chlorine required to kill the same number of microorganisms increases. With decreasing temperature, the same situation of increasing dosage to maintain the same kill is encountered. If the contact time is varied, then the dosage applied must also be changed. For example, to shorten the contact time the dosage would have to be increased.

● Combined available chlorine. This results from the presence of ammonia or organic nitrogen that will react to form simple chloramines. Thus the term *combined available chlorine* arises from the fact that the chlorine has combined with another substance. Chloramines are a slower acting and less active form of disinfectant. Therefore, a much higher concentration than that of free available chlorine is needed to produce the same germ-destroying effect. The specific chloramines present are also a function of pH.

Chlorine demand in most water is likely to be largely satisfied 10 minutes after chlorine is added. After the first 10 minutes of chlorination, disinfection continues but at a diminishing rate. A standard period of 30 minutes' contact time is used to assure that highly resistant or high disease-producing organisms have been destroyed, providing a high enough dosage has been applied. Given a sufficiently large chlorine content, and if certain other conditions are met, even such special water purification problems as the presence of amoebic cysts or schistosomes will be solved with the 30-minute contact period.

The efficiency of the chemical disinfection process is dependent upon numerous factors. They include the type and concentration of microorganisms, the pH and temperature of the water, the presence of interfering substances, and whether or not the organisms are protected from the disinfection solution by being embedded in tissue cells, or clumps of tissue cells, or other material. Therefore, various concentrations of disinfectants are required. Minimum concentrations of disinfectants are prescribed below. Higher concentrations may frequently be prescribed by the medical officer on the basis of his knowledge of endemic disease or local environmental conditions.

SEABEE-operated mobile and portable water treatment units use coagulation and filtration as a part of the treatment process. They are capable of a high degree of removal of particulate material. When those units are used, sufficient chlorine will be added to the water, preferably before coagulation, so the residual in the finished water after 30 minutes of contact will be at least as much as that indicated by the following table.

pH	30-Minute Free Chlorine Residuals in mg/1
5	0.75
6	0.75
7	1.00
8	3.00
9	5.00
10	5.00

If adequate provisions are not made for accurate and frequent measurement of pH, 5.00 mg/1 must be used. The following guidelines were used in developing the above table:

● The water to be treated would be natural surface or ground water of average composition and not grossly or deliberately contaminated.

● Water temperature would be above the freezing point.

● Treatment would consist of coagulation, sedimentation, and filtration through diatomaceous earth. Water plant operators would be well trained and dependable.

● The prescribed concentrations of free chlorine should provide a reasonable margin of safety for all bacteria and viruses pathogenic to man. Parasitic ova (eggs) would have been removed in the coagulation and filtration steps of the treatment process.

EMERGENCY TREATMENT METHODS

Emergency treatment methods using water sterilizing bags, canteens, and other water containers do not provide for removal of impurities by coagulation and filtration. The entire reliance for rendering the water safe for consumption is placed on the disinfection process. Sufficient chlorine is added to the water so the residual, after 30 minutes of contact, will be at least 5 ppm of total chlorine. Under certain conditions, such as the presence of highly resistant disease-producing microorganisms or adverse environmental conditions, the medical officer will designate such higher residuals as may be necessary.

Boiling is a quick means of disinfecting small quantities of water in the field by individual soldiers. It is likely that all bacteria that produce diseases in man are killed by pasteurization temperatures. But there are some resistant organisms, principally viruses (such as infectious hepatitis), for which water must be boiled to achieve inactivation. A practical minimum standard for altitudes from sea level to 25,000 feet is to bring the water to a rolling boil for 15 seconds. Longer boiling times may be prescribed by the medical officer on the basis of evidence that the minimum is not inactivating all pathogenic microorganisms. Upon cooling, the boiled water should be kept in a covered uncontaminated container. Boiling is obviously a difficult way to disinfect large quantities of water.

Breakpoint chlorination is the application of chlorine to produce a residual of free available chlorine with no combined chlorine present. As chlorine is added, the total residual increases gradually after the initial demand of the water has been satisfied. At some residual concentration, depending on the water treated, free available chlorine reacts with the remaining oxidizable substances (including combined chlorine), and the residual drops sharply. When all combined chlorine has been oxidized by reaction with free available chlorine, the residual, now consisting only of free available chlorine, rises again and continues to increase in direct proportion to increased dosage. The point at which the residual again begins to increase is the breakpoint.

Figure 9-18 shows four typical breakpoint chlorination curves. Note that the curve rises at almost a 45-degree angle after the breakpoint is reached. Reactions are most rapid at pH from 6.5 to 8.5 and with increasing temperatures.

Curve 1 shows a typical breakpoint for water containing a considerable amount of ammonia. During the initial upward rise, chloramines are first formed. The curve rises until sufficient free available chlorine is developed to react with chloramine; then it falls until a point where all ammonia compounds have been oxidized.

With less organic matter in the water, as in curves 2 and 3, free available chlorine is formed sooner, destroying chloramines formed at the early stage. This results in lower combined chlorine residuals and flatter curves before breakpoint.

With practically no organic matter, curve 4 shows the chloramines are neutralized at an early stage by the upswing of the curve.

For some waters containing complex organic compounds, several intermediate breakpoints occur.

Advantages of breakpoint chlorination are high bactericidal efficiency, long-lasting residuals, and low odor and taste characteristics. It can be used only if detention periods are long enough to develop free available chlorine residual. This varies with the organic content of water. In some cases the treated water must be open to the air to permit escape of chloroorganic gases formed.

Tests for ammonia nitrogen will assist in determining the breakpoint. In practice, 10 to 25 times as much chlorine as ammonia nitrogen content may be needed to reach the breakpoint. Breakpoint chlorination, before instead of after filtration, has been found desirable. In surface water supplies with widely varying ammonia nitrogen content, the breakpoint chlorination should not be used unless trained assistance is available to make frequent tests for the breakpoint. With such water quality, the breakpoint curve can change radically in a short time.

Superchlorination is the application of more chlorine than needed for the chlorine residual

essential to marginal chlorination. The surplus, which is used to control odors and tastes, is later removed by dechlorination. This method is particularly valuable in surface waters with variable ammonia and organic content. Sulfur dioxide reacts with chlorine to form acids that are neutralized by the natural alkalinity of the water. Sulfur dioxide is fed by equipment similar to that used for chlorine feeding. Activated carbon absorbs the excess chlorine, while aeration removes it by dissipating it to the atmosphere.

Water Purification System (3000D)

The 3000D Water Purification System was developed to provide a fully self-contained water purification unit for purifying turbid and bacteria-polluted water. The design of the unit allows for increased efficiency, mobility, and cost effectiveness. The unit provides trouble-flee water purification at the rate of 3,000 gph.

There are four modular components located within a single frame: diesel-powered pump, chlorinator control, filter, and supplies to produce 20,000 gallons of potable water. Subsequent water processing requires only Diatamatious earth, chlorine, and diesel fuel. Each module may be operated independently in or out of the frame by one person.
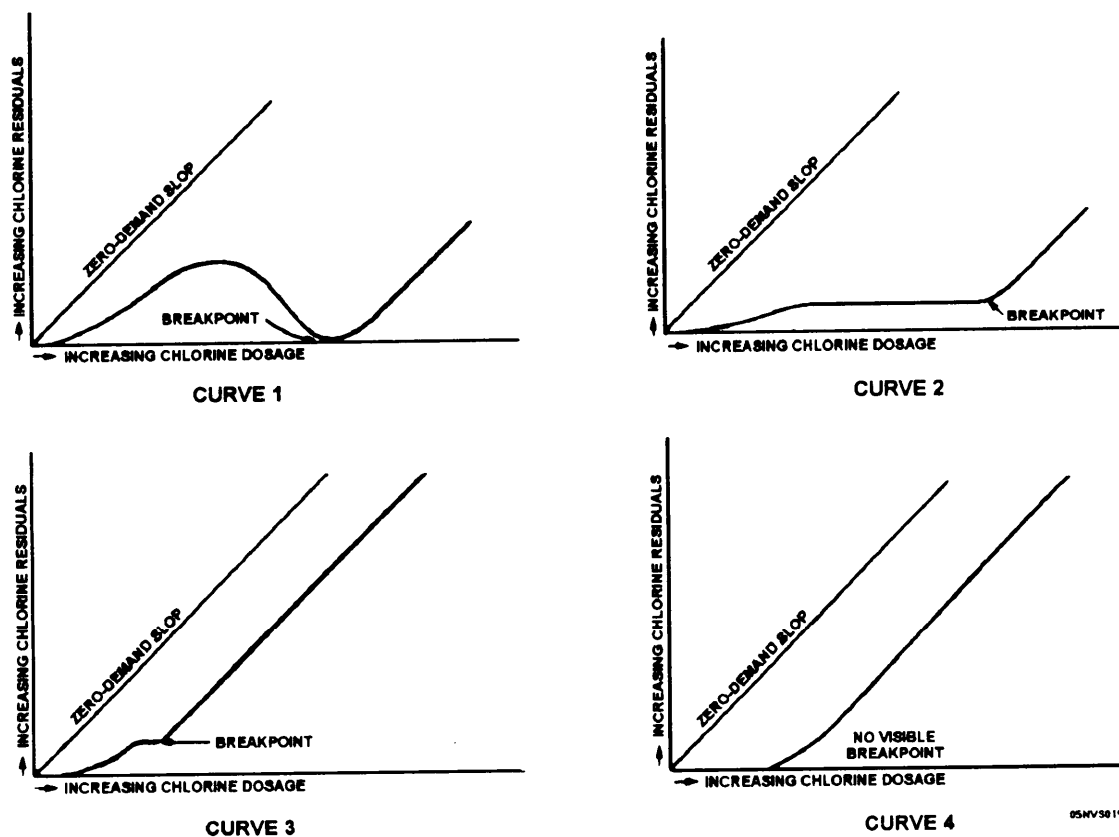

Figure 9-18.—Breakpoint chlorination curves.